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Effects of Land Use and River Seepage on Groundwater Quality in Hall County, Nebraska

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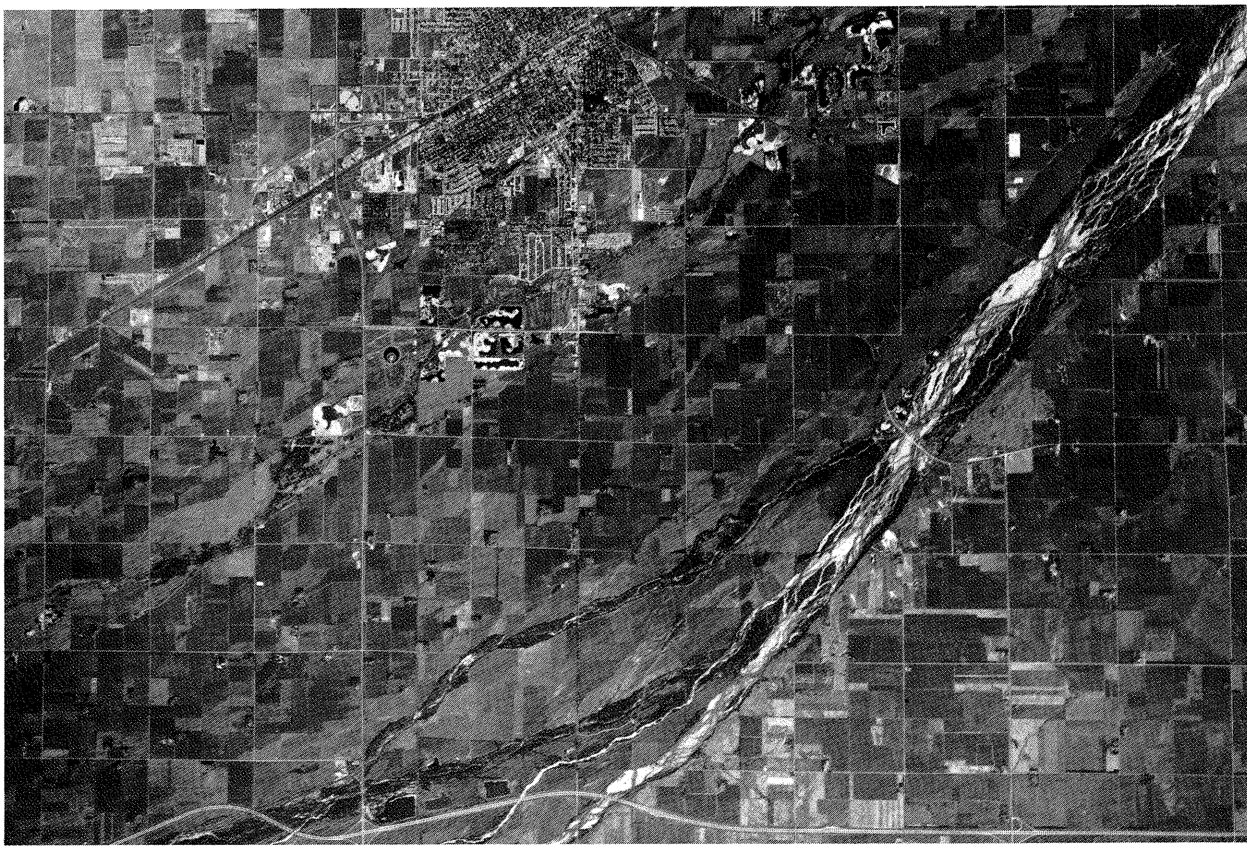

NEBRASKA WATER SURVEY PAPER NUMBER 38

Prepared by the Conservation and Survey Division, Institute of Agriculture and Natural Resources, The University of Nebraska–Lincoln

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EFFECTS OF LAND USE AND RIVER SEEPAGE
ON GROUNDWATER QUALITY IN HALL COUNTY, NEBRASKA

ABSTRACT

Zones of differing groundwater quality have been delineated in Hall County. Basic data available for these delineations consisted primarily of the following: 322 nitrate analyses by the Hall County Health Department and the Hall County Cooperative Extension Service; 161 determinations of pH, temperature, specific conductance, chloride, sulfate, phosphate, and nitrate by the University of Nebraska's Conservation and Survey Division; and all relevant analyses by the U.S. Geological Survey during 1971. Also available were monthly analyses of nitrate, phosphate, and chloride and occasional analyses of sulfate in water from five wells in the vicinity of Grand Island.

The average concentration of sulfate in groundwater beneath the Platte River bottomland, an area of about 135 square miles, approaches the upper limit of 250 mg/l that is recommended by the U.S. Public Health Service for drinking water. This rather high average concentration appears to be related to infiltration of river water, samples of which contained about 250 mg/l sulfate.

A smaller groundwater zone, between Wood River and Cairo on the broad terrace north of the river, contains sulfate much in excess of the recommended upper limit. Sulfate concentrations greater than 500 mg/l characterized water from several wells tapping this zone. Because the overlying Wood River soils include layers

of gypsum, it is believed that the soils are the source of the excess sulfate in the groundwater zone. Leaching of the gypsum probably has been accelerated by infiltrating irrigation water.

Several groundwater zones containing nitrate in excess of the 45 mg/l recommended upper limit are located on the broad terrace north of the Platte River. Hord-Hall soils overlie the greater part of these zones and Ortello-Thurman soils overlie most of the remainder. Because Hord-Hall soils are slightly acidic in the upper part, applied anhydrous ammonia fertilizer probably exists mostly in the ammonium form until it is either nitrified and used by the crop or is leached downward through the moderately permeable subsoil to the zone of saturation. Ortello-Thurman soils also have moderate to rapid permeability and, likewise, infiltrating water readily transports nitrate to groundwater. Available evidence indicates that leachate from manure accumulations, particularly in abandoned feedlots, and from septic tanks accounts for some locally high concentrations of nitrate. Seepage from the Platte River is shown to have a diluting effect on the nitrate influx to bottomland groundwater.

A low average nitrate concentration characterizes groundwater overlain by Wood River soils, even though agricultural practices on these soils are about the same as on Hord-Hall and Ortello-Thurman soils. Wood River soils are alkaline and thus tend to release ammonia to the atmosphere. Furthermore, their subsoils contain considerable clay, which would tend to retard infiltrating nitrate-bearing water. It is hypothesized that within the clay layers nitrate would be reduced to the ammonium ion and fixed.

The tendency for nitrate concentrations to increase with time indicates that the nitrate problem will become progressively worse.

ACKNOWLEDGMENTS

The author's wife, M. E. Spalding, contributed considerably to the organizational phase of this study and also made many helpful criticisms of the manuscript. Also contributing helpful suggestions were M. J. Ellis and R. A. Engberg of the U.S. Geological Survey in Lincoln, Nebraska; V. H. Dreeszen, J. A. Elder, and P. W. Huntoon of the University of Nebraska's Conservation and Survey Division; and F. J. Otradovsky of the U.S. Bureau of Reclamation at Grand Island. Others of the Conservation and Survey Division helped by reviewing, editing, and typing the manuscript and by drafting the illustrations. Principal among these were Ray Bentall, C. K. Peterson, D. R. Peabody, J. P. Leach, H. T. Koch, F. M. Faulkner, and B. A. Forcé.

INTRODUCTION

Excessive concentrations of nitrate and sulfate in drinking water are hazards to health. This baseline study of water quality in Hall County confirms the existence of zones of high nitrate and sulfate in the groundwater reservoir, which is the source of all water consumed by rural and urban residents of the county. Such zones are predicted to migrate and disperse, because groundwater moves in response to both the gentle natural hydraulic gradient and to the steeper hydraulic gradients in the immediate vicinity of wells that are being pumped. Thus, a problem that now exists in one locality will cause a problem in another locality at some future time. Furthermore, repeated analyses of groundwater at identical locations have indicated that nitrate concentrations are increasing annually; for this reason, a continual source of pollution is implied.

The health hazards arising from excesses of nitrate in groundwater are much more serious than those from high sulfate. Comly (1945) reported that nitrate has been associated with an infant blood disorder called methemoglobinemia. About 2,000 cases of methemoglobinemia and 160 fatalities during the period 1945-63 have been reported in North America and Europe by Walton (1951), Sattelmacher (1962), and Simon *et al*. (1964). These cases were associated directly with high concentrations of nitrate in drinking water. Sattelmacher (1962) reported cases of methemoglobinemia in infants whose drinking water had no more than 39.6 mg/l (milligrams per liter) nitrate; however, a large majority of cases were associated with nitrate concentrations greater than 45 mg/l.

Apparently infants are not equally subject to nitrate poisoning. At present the biochemical reactions involved in selective susceptibility to methemoglobinemia are not completely understood.

In order to protect the majority of infants, the U.S. Public Health Service (1962) recommended an upper limit of 45 mg/l nitrate in drinking water. This limit has no safety factor; in fact, after studying 139 case histories in Wisconsin, Bosh et al. (1950) recommended that the upper limit should be lowered to 30 mg/l nitrate. Campbell et al. (1954) reported that nitrate concentrations greater than 1,000 mg/l have been associated with cattle fatalities, thus showing that nitrate in excessive concentrations is hazardous to nonhumans also.

High concentrations of sulfate in drinking water can have a diarrheic effect. Peterson (1951) reported that water having a sulfate concentration greater than 750 mg/l has a laxative effect and water having less than 600 mg/l usually does not. However, Moore (1952) showed that in the presence of magnesium ions, laxative effects occur at lower sulfate concentrations. The recommended upper limit for sulfate in drinking water was established at 250 mg/l to give a reasonable margin of safety. In general, people and animals and fowl soon adjust to the laxative affect when sulfate concentrations range from 250-1,000 mg/l.

Chemical analyses of water from 161 wells and from several stream sites in Hall County, Nebraska, were available from earlier investigations. Many of these analyses were made in connection with water-quality studies done by Piskin (1973) and Atkinson (1973), both of whom reached conclusions at variance with those presented in this paper. Although this paper pertains primarily to nitrate and sulfate in the groundwater of Hall County, it also refers to chloride and phosphate and selected other dissolved constituents. In effect, it is a reevaluation and reinterpretation of certain aspects of all the pertinent water-quality data on record for Hall County.

In this report, nitrate is expressed not as nitrate-nitrogen but as nitrate itself. To convert nitrate to nitrate-nitrogen, divide by 4.4. Temperature and water-quality data are expressed in metric units and other data are given in English units. To convert English units to metric units, the reader may wish to refer to Appendix A for a listing of conversion factors.

GEOGRAPHY AND GEOHYDROLOGY OF HALL COUNTY

Hall County, an area of 540 square miles (345,600 acres), is in south-central Nebraska (fig. 1). Except for its northwest corner and southeastern part, the county is in the Middle Platte River Basin as defined by the Nebraska Natural Resources Commission. The Platte River transects the county, entering near its southwest corner and leaving at the middle of the east county line. About three-fourths of the county lies within the broad river valley.

The population of Hall County is approximately 40,910 (U.S. Census Bureau, 1971). Grand Island, the county seat, is the largest town in the county and in 1970 had a population of 31,269. Other towns, in order of descending population, are Wood River, Cairo, Doniphan, and Alda.

Hall County is centrally located in the Loess Plains District of the High Plains Section of the Great Plains Physiographic Province (Fenneman, 1938). Generally the Loess Plains District consists of gently sloping interstream uplands separated by wide valleys. These valleys are occupied by shallow, braided streams that are bordered by low terraces.

As shown in figure 2, the greater part of Hall County consists of three physiographic regions: bottomland, terrace, and upland. The bottomland bordering both sides of the Platte River is nearly flat, 4 to 10 miles wide, and nowhere more than 10 feet above the river bed. A low escarpment north of and parallel to the Platte River is the outer edge of a broad low terrace that also is nearly flat and lies 25 to 40 feet above the bottomland. Only a very narrow terrace borders the south side of the bottomland. Uplands in the

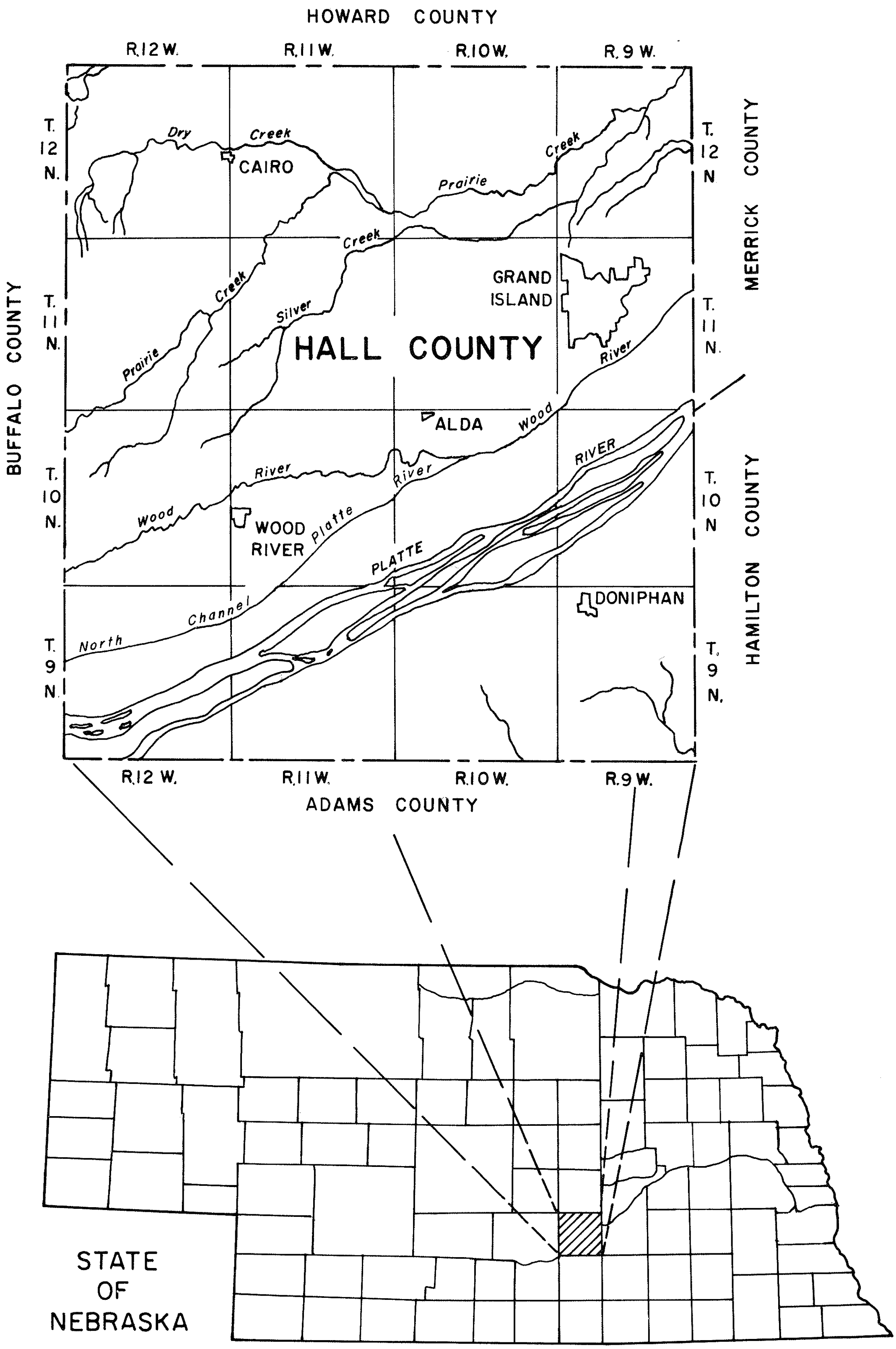

Figure 1.--Index map of Hall County, Nebr.

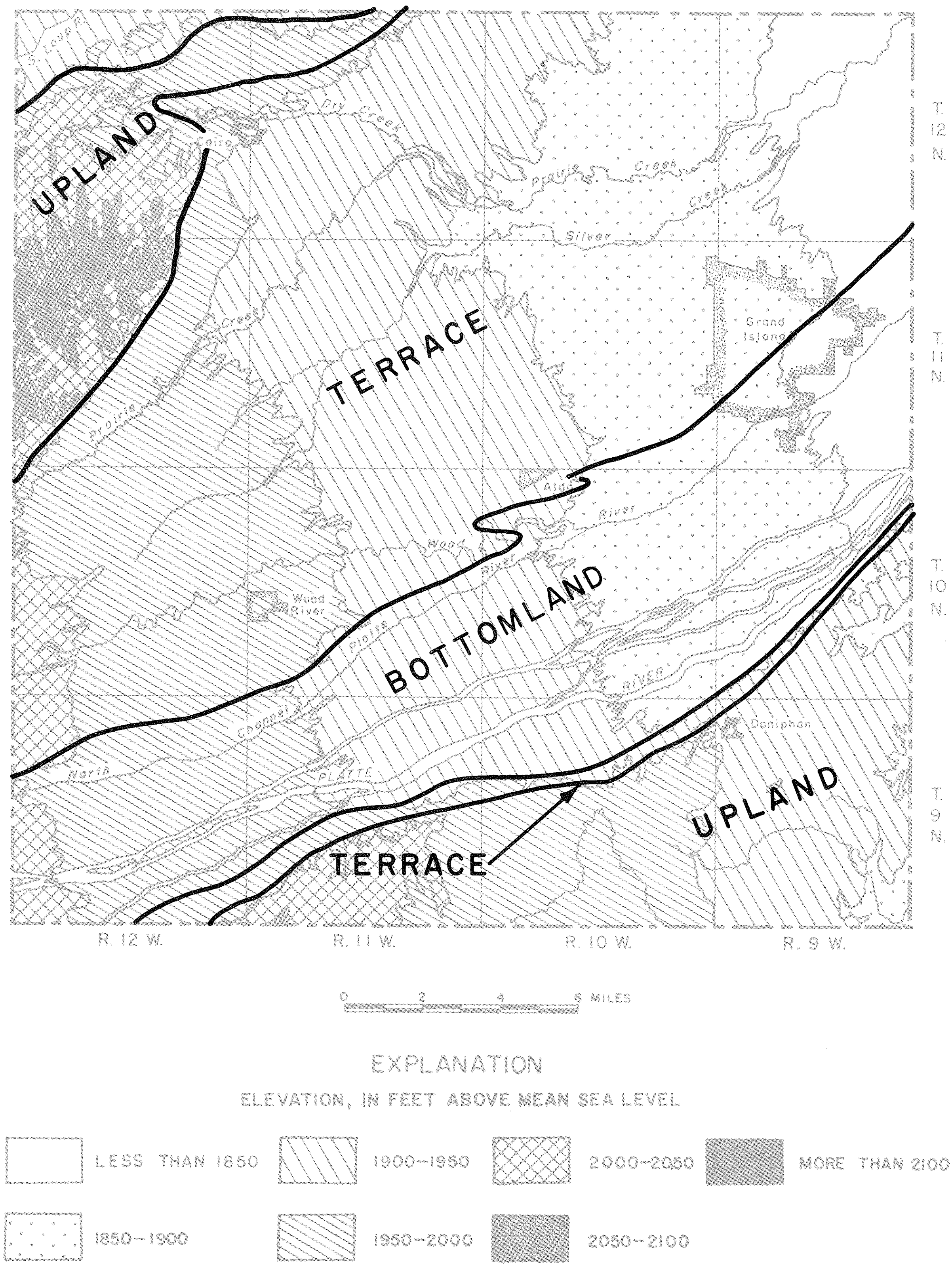

Figure 2.--Principal physiographic features of Hall County.

northwestern and southeastern parts of the county lie 40 to 120 feet above the Platte River bottomland. An area of about 6 square miles in the northwest corner of the county is in the South Loup River valley.

Hall County has a subhumid climate, the average annual potential evaporation being significantly greater than the average annual precipitation. According to the Climatic Atlas of the United States (U.S. Dept. Commerce, Environmental Data Service, 1968, p. 63), class A pan evaporation and lake evaporation average 65 and 45 inches per year, respectively, and according to climatological data for the period 1931-70 (U.S. Dept. Commerce, National Weather Service, annual summaries) precipitation on Hall County averages 22.44 inches per year, or 1.87 feet per year. Thus, prior to the development of irrigation in the county, only the precipitation that infiltrated below root depth or which contributed to the surface outflow from the county could escape early return to the atmosphere. Now that water is pumped from wells to irrigate 168,700 acres (State /Nebr./ - Federal Div. Agr. Statistics, 1971-72, 1973), considerably more water is available for evapotranspiration than formerly. The author estimates that 687,900 acre-feet of water per year currently are returned to the atmosphere; this estimate is based on the following data:

Evapotranspiration rates

(F. J. Otradovsky, personal communication)

	Feet per year
Bottomland:	
Nonirrigated	1.69
Irrigated	2.39
Terrace:	
Nonirrigated	1.74
Irrigated	2.39

The estimated value for annual evapotranspiration exceeds the average annual precipitation, which amounts to 646,300 acre-feet, by 41,600 acre-feet.

Water loss to surface runoff is small in Hall County because, in a large part of the county, the terrain is nearly flat and soils have moderate to moderately rapid permeability. F. J. Otradovsky (personal communication) estimated that the average rate of loss via runoff from irrigated and dryland soils on the terrace is 0.044 and 0.033 feet per year, respectively. He also estimated average runoff from irrigated and dryland soils on the bottomland to be 0.009 and 0.045 feet per year, respectively. From these data, the author estimates that total runoff amounts to 12,000 acre-feet per year.

At any one time there are approximately 8.1 million acre-feet, or 2.6 trillion gallons, of groundwater beneath Hall County. This volume has a tremendous potential for diluting pollutants from surface sources. Groundwater is not static but is continually moving into the county from the west and leaving the county beneath both its east boundary and the eastern part of its south boundary.

An estimate of the amount of groundwater inflow to and groundwater outflow from the county can be calculated by using the formula $Q=TW(dh/dl)$ where Q is the flow, T is the transmissivity, W is the width of the cross section through which flow occurs, and dh/dl is the hydraulic gradient. Transmissivities along the west and east boundaries have been computed by Keech and Dreeszen (1964) from logs of test holes drilled to the base of the aquifer at 3-mile intervals. Estimated annual inflow from the west is 12,500 acre-feet, and estimated annual outflow to the east and southeast is 22,000 acre-feet.[1/]

The average velocity of groundwater movement can be computed by use of the formula $v=Q/pA$, where v is the velocity, Q the flow, p the porosity, and A the cross-sectional area. Use of 0.30 as a reasonable average value for porosity and the cross-sectional area shown by Keech and Dreeszen (1964, fig. 2, B-B') indicates that the average velocity of groundwater movement is 2 to 3 feet per day.[2/]

1/ See Appendix B (1.).

2/ See Appendix B (2.).

In terms of a chemical pollutant, this means that the front margin of a plume of pollutant advances in the direction of groundwater flow at a rate of about 1 mile in 5 years.

If only precipitation, evapotranspiration, and runoff are considered, the annual deficit for Hall County is about 53,600 acre-feet of water. This combined with an estimated input of 9,500 acre-feet, obtained from subsurface flow computation, indicates that a source of approximately 63,100 acre-feet of water must be present in Hall County if a steady-state water table is to be maintained. Although a small quantity comes from the Wood River, the only source capable of yielding large quantities of water to Hall County is the Platte River.

The Platte River flows on permeable deposits and is in hydraulic connection with the groundwater reservoir. Lugn and Wenzel (1938) pointed out that the Platte River is either a losing or a gaining stream depending on the groundwater levels in the vicinity. Keech (1952) also concluded that the river alternately loses water to and gains water from the adjacent groundwater reservoir. Discharge measurements by the U.S. Geological Survey indicate that the Platte River commonly is a losing stream between the Odessa (Buffalo County) and Grand Island gauging stations. For example, the net loss between these two gauging stations during the 1970 calendar year is reported to have been 89,000 acre-feet (U.S. Geol. Survey ann. rept., 1972) despite intervening gains by inflow from North Dry Creek and by influent seepage from the Tri-County Irrigation Project. For 1970 the U.S. Geological Survey (1972) reported inflow of 8,440 acre-feet from North Dry Creek, and F. J. Otradovsky (personal communication) estimated 60,000 acre-feet of seepage into the Platte from the groundwater mound beneath the Tri-County Irrigation Project. Thus, the total loss from the Platte River between the two gauging stations in 1970 was approximately 160,000 acre-feet of water. This amounts to an average loss of about 2,700 acre-feet per mile. At present a lack of strategically placed river-stage and groundwater-level monitoring sites makes it impossible to determine accurately how much of this water is being lost to the area north of the river in

Hall County; however, because water levels are relatively static in the county, it appears that the figure is close to 50,000 acre-feet per year.

Further evidence that the Platte River is an important source of recharge to the groundwater reservoir is provided by the water-table configuration map (fig. 3). Because the river in south-eastern Buffalo County and across the full width of Hall County is higher than the adjacent water table, the river loses water by seepage. The direction of water movement away from the river is illustrated by the flow lines originating at the river's edge. It is apparent from the flow lines crossing the west boundary of Hall County that part of the groundwater flow into the county is seepage from the Platte River in southeastern Buffalo County.

The Wood River, which is joined by the North Channel of the Platte River near Alda, is a losing stream west of Alda in Hall County. The losses include both evaporation and seepage, of which the latter represents about 80 percent of the loss (P.W. Huntoon, personal communication). Measured losses between Gibbon and Alda are highly variable, ranging from 0 to nearly 5,000 acre-feet in the period 1961-70; the measured loss in the 1970 calendar year was 890 acre-feet (U.S. Geol. Survey ann. rept., 1972). Actual losses ordinarily are somewhat greater than measured losses because sewage wastes from the towns of Shelton and Wood River and from several small tributaries enter the reach between the gauging stations. Average annual losses by seepage to the groundwater reservoir are estimated to be 1,620 acre-feet.

At times of low flow a considerable fraction of the water in Wood River is effluent from the sewage treatment plant at the town of Wood River. This effluent, which contributes about 69.5 acre-feet of sewage annually, represents a maximum of only about 4 percent of the total seepage losses from the Wood River. Another effluent contribution, approximately 58 acre-feet annually, is introduced from Shelton in Buffalo County and may be lost primarily as seepage east of Shelton in Hall County. The potential for pollution of the groundwater due to infiltration of the sewage effluent will be evaluated thoroughly in a later section of this report.

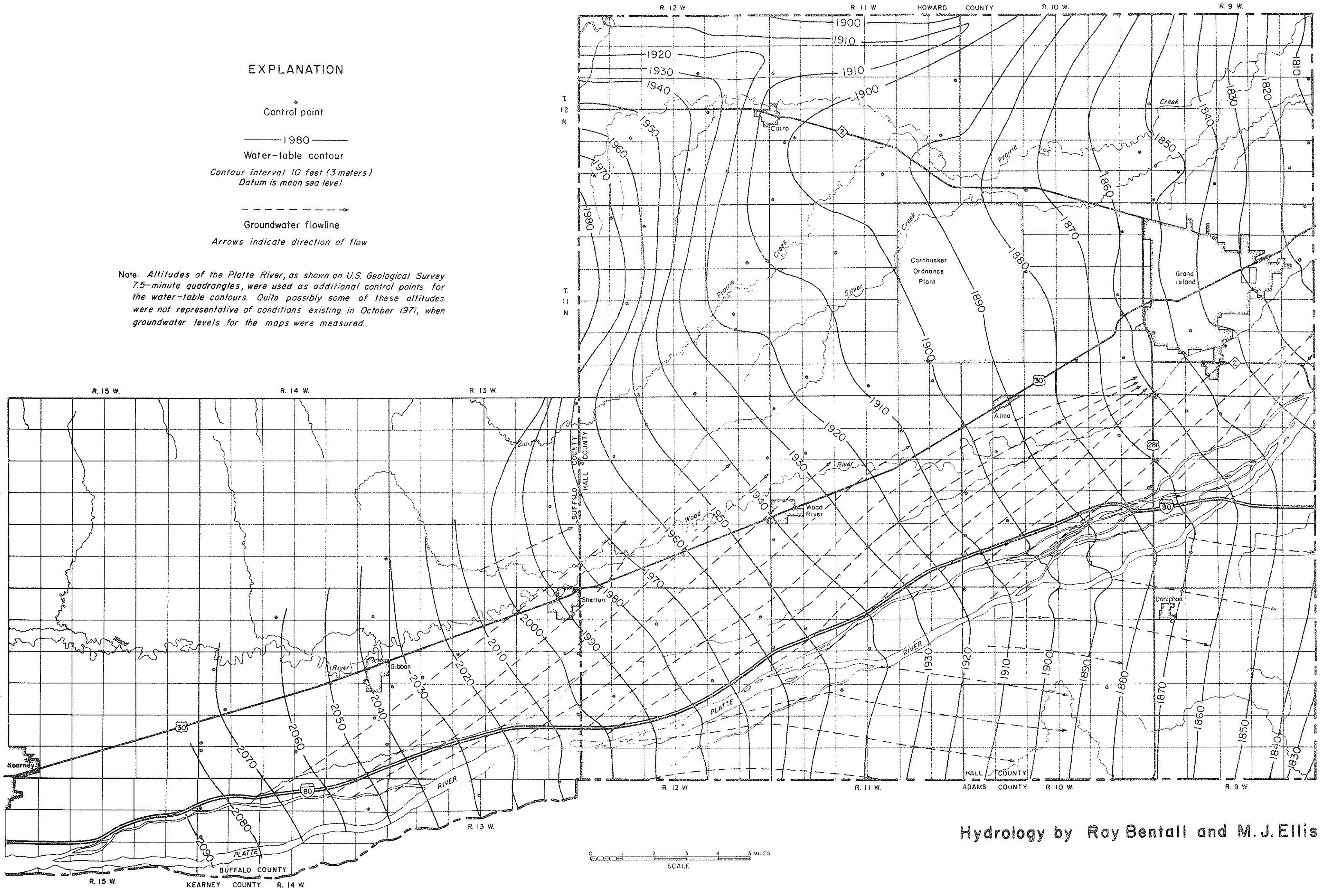

Figure 3.--Configuration of the water table in Hall County and southwestern Buffalo County.

Despite the recharge due to seepage from streams and to infiltration of precipitation and excess irrigation water, Hall County generally has a slight loss of groundwater annually. The author estimates the loss to be about 20,000 acre-feet per year. If uniformly distributed throughout the county, this loss would cause the water table to decline at the rate of 0.3 foot per year. However, records of water-level changes in observation wells scattered throughout the county indicate that net water loss in the Platte River valley part of Hall County tends to be concentrated in three areas on the terrace north of the Platte River and one area south of the river (fig. 4). Hydrologically, it is fortunate for Hall County that floods, early snowmelts, and precipitation have the demonstrated potential to restore lowered water levels. For example, the hydrograph in figure 5 shows that flood water in 1967, early snowmelt in 1969, and precipitation that exceeded crop needs during the growing seasons of 1972 and 1973 infiltrated to the water table.

The sediment column in Hall County consists of soil, unsaturated fluvial and eolian deposits, saturated fluvial and eolian deposits, and saturated bedrock. The first two consist of Quaternary deposits; the third consists partly of Quaternary deposits and partly of the Ogallala Formation of Pliocene (Tertiary) age; and the fourth consists of consolidated marine strata of the Upper Cretaceous series. Because the marine shales are very fine textured and ordinarily can yield little or no water to wells, drilling for irrigation supplies generally ends short of or at the upper surface of those beds.

As shown by figure 6, soils in Hall County have been grouped by Yost et al. (1962) into 11 associations. Two of these are on bottomland along the Platte River, six are on the terraces bordering the bottomland, and the remaining three are on the upland. The bottomland and terrace soils are of particular interest in this study.

Bottomland soils are in either the Platte-Sarpy association or the Wann-Leshara-Cass association. The former are mostly too shallow or too wet for cultivation but are highly suitable for permanent pasture. The latter are mostly cropland and a large

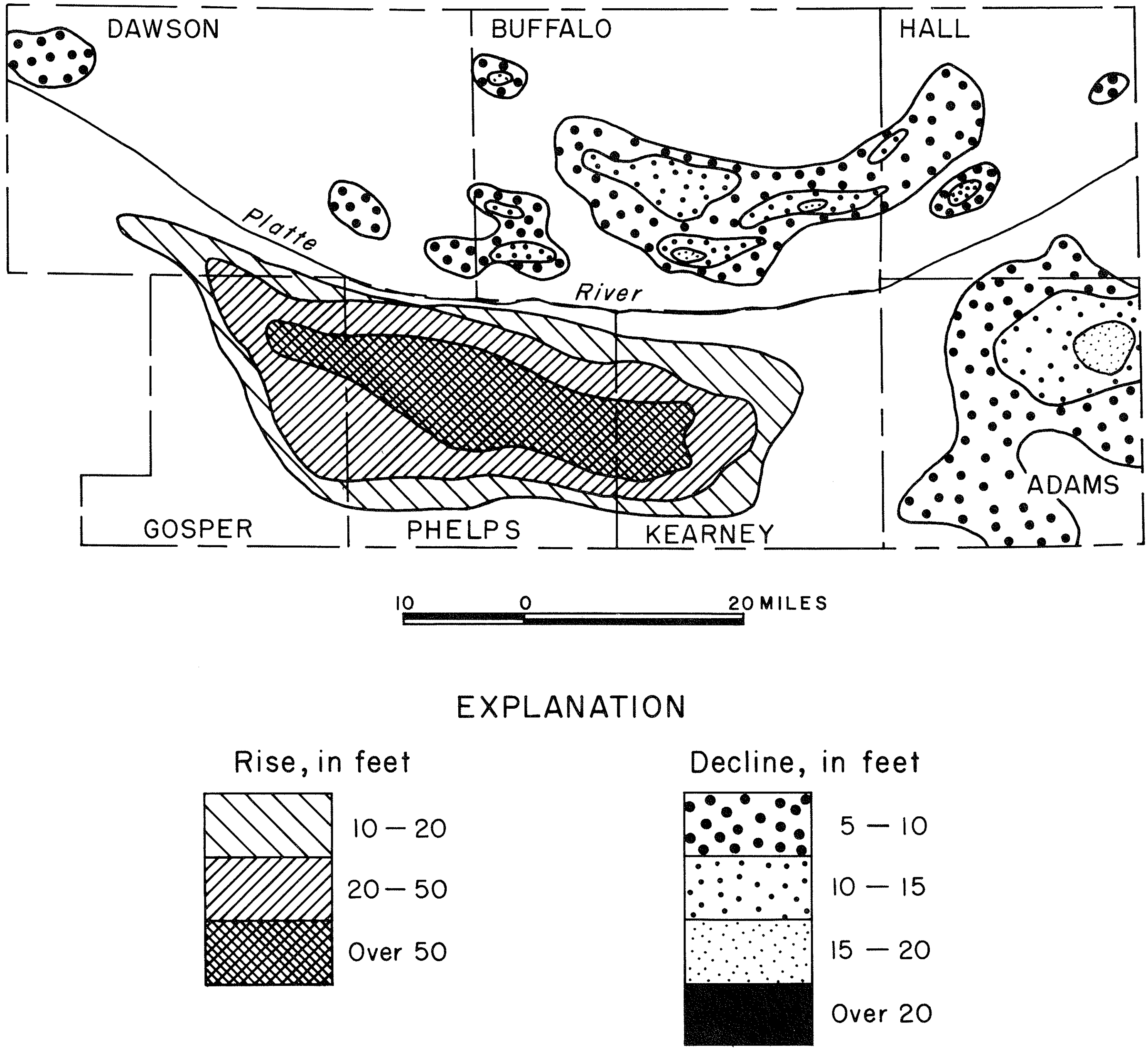

Figure 4.--Areas of water-table rise and decline from assumed pre-irrigation water-table position.

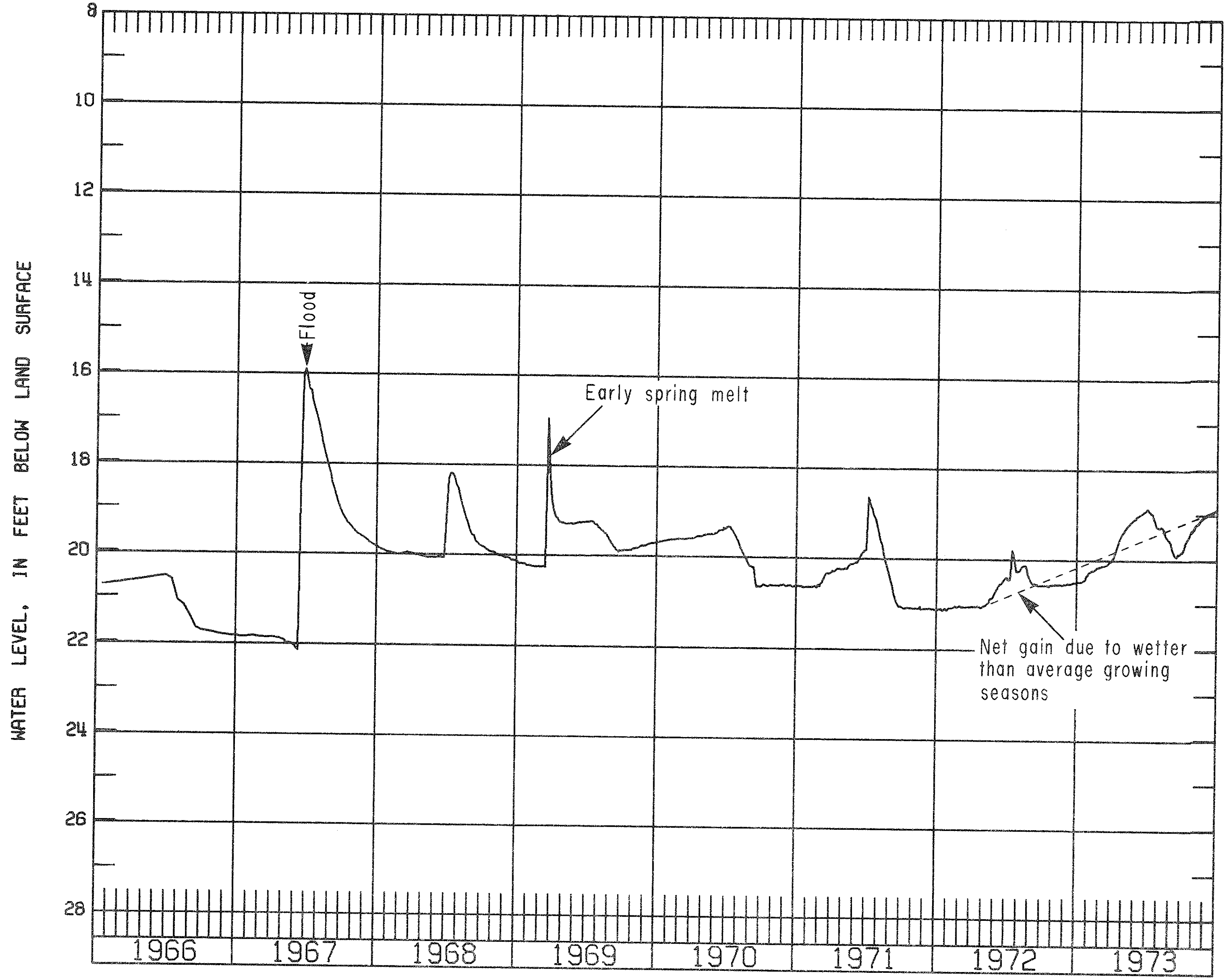

Figure 5.--Hydrograph of well 11N-11W-25CC.

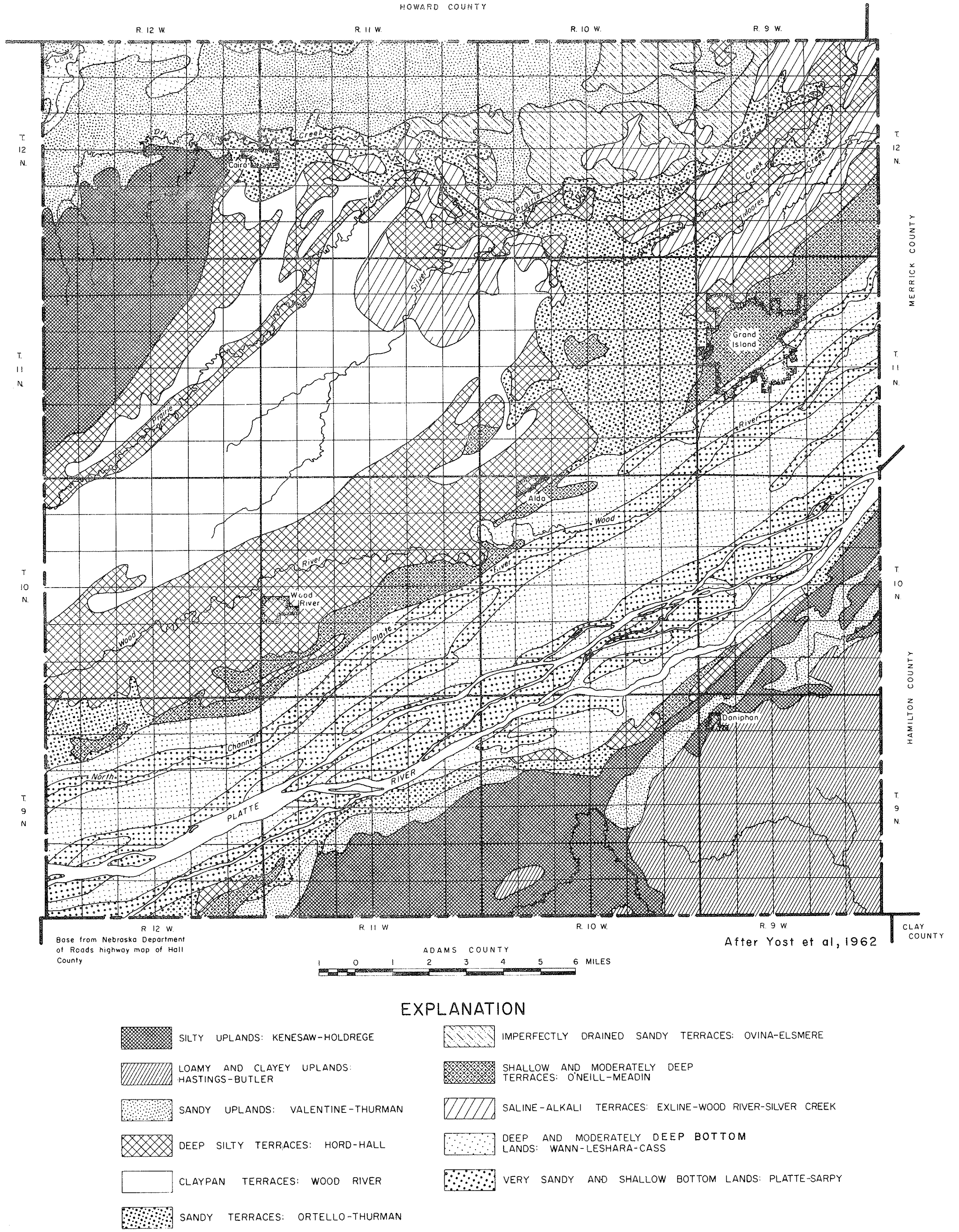

Figure 6.--Soil associations in Hall County.

acreage is irrigated; they are naturally well drained to imperfectly drained.

Four of the associations on the principal terrace are intensively cultivated and are in large part irrigated. The Hord-Hall association consists of soils that are among the best in the county for agriculture, being high in natural fertility and having medium internal drainage. Soils of the Wood River association also are high in natural fertility but have much slower internal drainage; they have a claypan subsoil that in many places includes a saline layer. Both the Ortello-Thurman and the O'Neill-Meadin associations consist mostly of soils that are fertile but are so well drained that they tend to be droughty where not irrigated.

The two remaining soil associations on the terraces are the Ovina-Elsmere association and the Exline-Wood River-Silver Creek association. Neither is very well suited to crop production because of imperfect drainage. Soils of the Ovina-Elsmere association have a high water table and in some years are so wet that seed-bed preparation is delayed and cultivation is impossible. The Exline-Wood River-Silver Creek association also is characterized by a generally high water table. Furthermore, the subsoil is clayey and in most places either is moderately to strongly saline-alkaline or contains large amounts of free lime. Numerous alkali spots on Exline and Wood River soils are difficult to cultivate; they occur in shallow depressions commonly called buffalo wallows.

Upland soils comprise the Kenesaw-Holdrege, Hastings-Butler, and Valentine-Thurman associations. Of these, the first two developed in thick loess deposits and are well suited to cultivated crops. The third, which consists of soils that developed in wind-deposited sand, generally is not suitable for cultivation but produces an abundance of good forage. The depth to the water table below upland soils is much greater than below terrace and bottomland soils.

Because the water table rises and declines with changing conditions of recharge and discharge, the thickness of the unsaturated and saturated zones varies accordingly. In many places on the bottomland and in some places on the principal terrace, the unsaturated zone is never more than a few feet thick; the water table sometimes rises into the soil and occasionally the unsaturated zone is eliminated. At other places the thickness of the unsaturated zone is always more than a few feet and, beneath the uplands, it may be greater than 100 feet.

Sediments composing the unsaturated zone are significant in that water infiltrating from the surface must pass through them to reach the zone of saturation. Where moderately to rapidly permeable, these sediments freely transmit water downward, ordinarily without significant effect on the chemical quality of the water. On the other hand, where these sediments are fine textured, they not only impede infiltration of water but commonly effect some change in water quality. As shown later in this report, certain differences in the chemical quality of the groundwater in Hall County can be attributed in large measure to differences in the transmitting characteristics of the soil and the underlying unsaturated zone.

The saturated fluvial and eolian deposits extend throughout the county and range in thickness from about 80 to 310 feet. Those that are Quaternary in age consist of clay, silt, sand, and sandy gravel. Beneath them in about three-fourths of the county (fig. 7) is the Ogallala Formation, which is composed principally of clay and claystone, silt and siltstone, and sand and sandstone. All these sediments were derived from western sources and consist principally of quartz, feldspar, and fragments of igneous and metamorphic rocks. Together, the Quaternary deposits and Ogallala Formation can be regarded as a single aquifer. At any given location in the county, the maximum potential yield of a well is a function of the thickness of the water-bearing, coarser-textured sediment (sand, sandy gravel, and sandstone) penetrated in drilling the well. According to Keech and Dreeszen (1964), this thickness differs from place to place and ranges from about 40 feet to as much as 225 feet. All wells in the county obtain water from either the Quaternary deposits alone or from the Quaternary deposits and Ogallala Formation combined. Possibly a few wells obtain more water from the Ogallala than from the Quaternary deposits, but none obtains its entire supply from the Ogallala Formation. Thus, the water-quality data on which this study is based represent either water from only the Quaternary deposits or a mixture of water from the Quaternary deposits and Ogallala Formation combined.

The bedrock surface, or base of the principal aquifer, truncates two westward-dipping stratigraphic units of Late Cretaceous age, the younger of which is the Pierre Shale and the older the Niobrara Formation. Figure 7 shows the extent of the areas where these units form the uppermost bedrock; it also shows the configuration of that surface by means of contour lines. Shaped by erosion during the post-Pierre and pre-Ogallala span of geologic time, the bedrock surface consists of valleys and intervalley uplands.

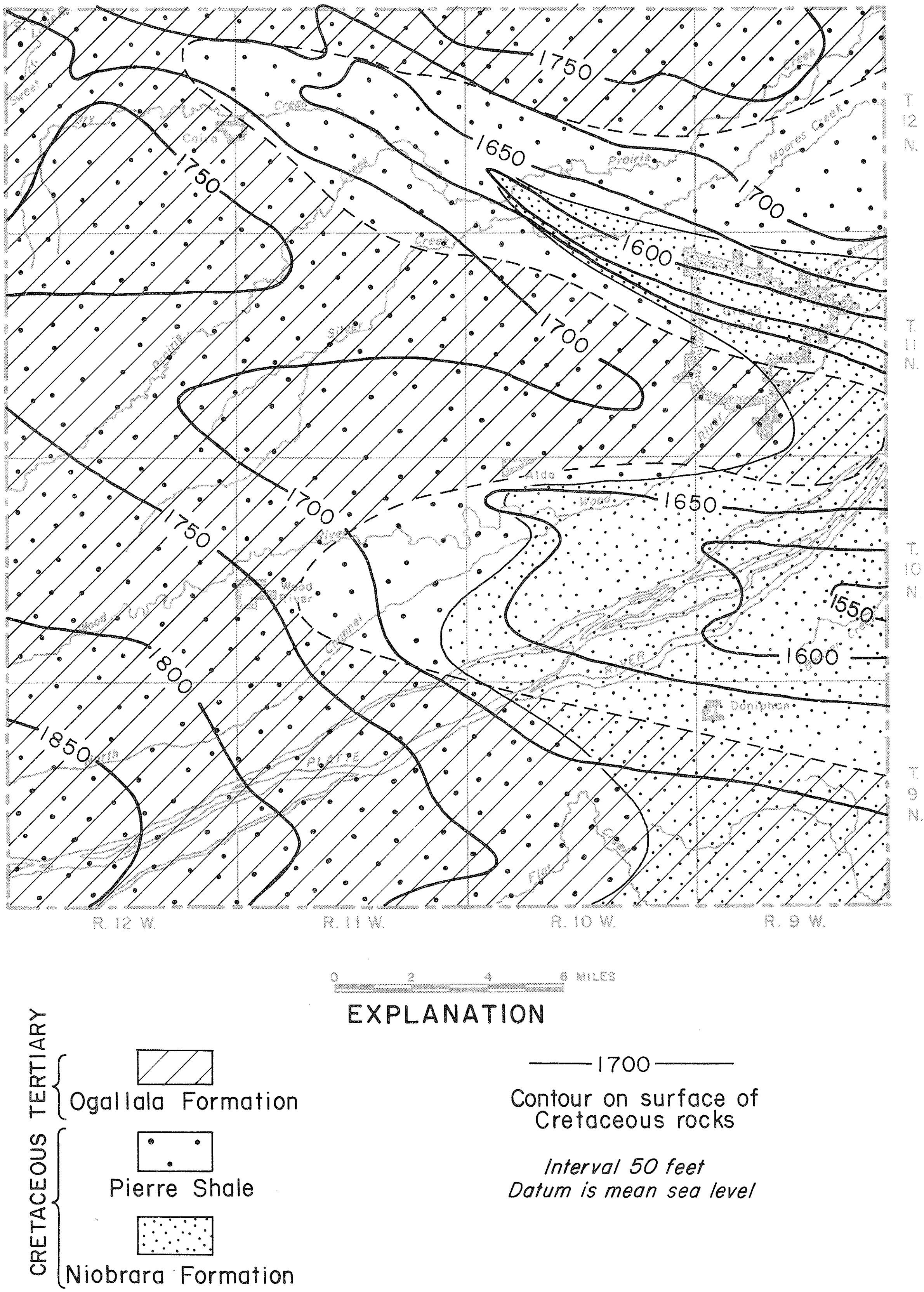

Figure 7.--Areal distribution and configuration of Cretaceous rocks and extent of Ogallala Formation of Tertiary age.

GROUNDWATER QUALITY

The economy of Hall County is based almost exclusively on raising irrigated corn and fattening cattle in feedlots. Both activities have shown appreciable gains in the past ten years (fig. 8) and both are major sources of nutrients to the environment. Of the major nutrients, nitrogen is the most important in considering groundwater quality. Briefly, soluble nitrogen in the form of nitrate readily infiltrates to groundwater, and an excess of nitrate in groundwater is a health hazard. On the other hand, phosphorus as soluble phosphate has a much lower capacity to infiltrate to groundwater and is not a health hazard.

The crude estimates in table 1 show that inorganic fertilizers were responsible for 65 percent of the nitrogen added to Hall County soils in 1971. An additional 27 percent of the nitrogen introduced to the soils was in the form of wastes produced in 47 operating feedlots that contained about 110,000 head of cattle at any one time. It is estimated that 92 percent of the nitrogen gain to Hall County in 1971 was a direct result of the county's corn agriculture (corn constitutes about 98 percent of the total crop production) and its allied feedlot industry. Nitrogen is lost from Hall County soils via the atmosphere, runoff, and crop utilization. Approximately 48 percent of the nitrogen utilized by plants is recycled to Hall County feeders. In total there was approximately a 19,000-ton N gain to Hall County soils in 1971.

Phosphate was used to a lesser extent than nitrate; about 736 tons of superphosphate $[Ca(H_2PO_4)_2]$ and 21,460 tons of dry mixed

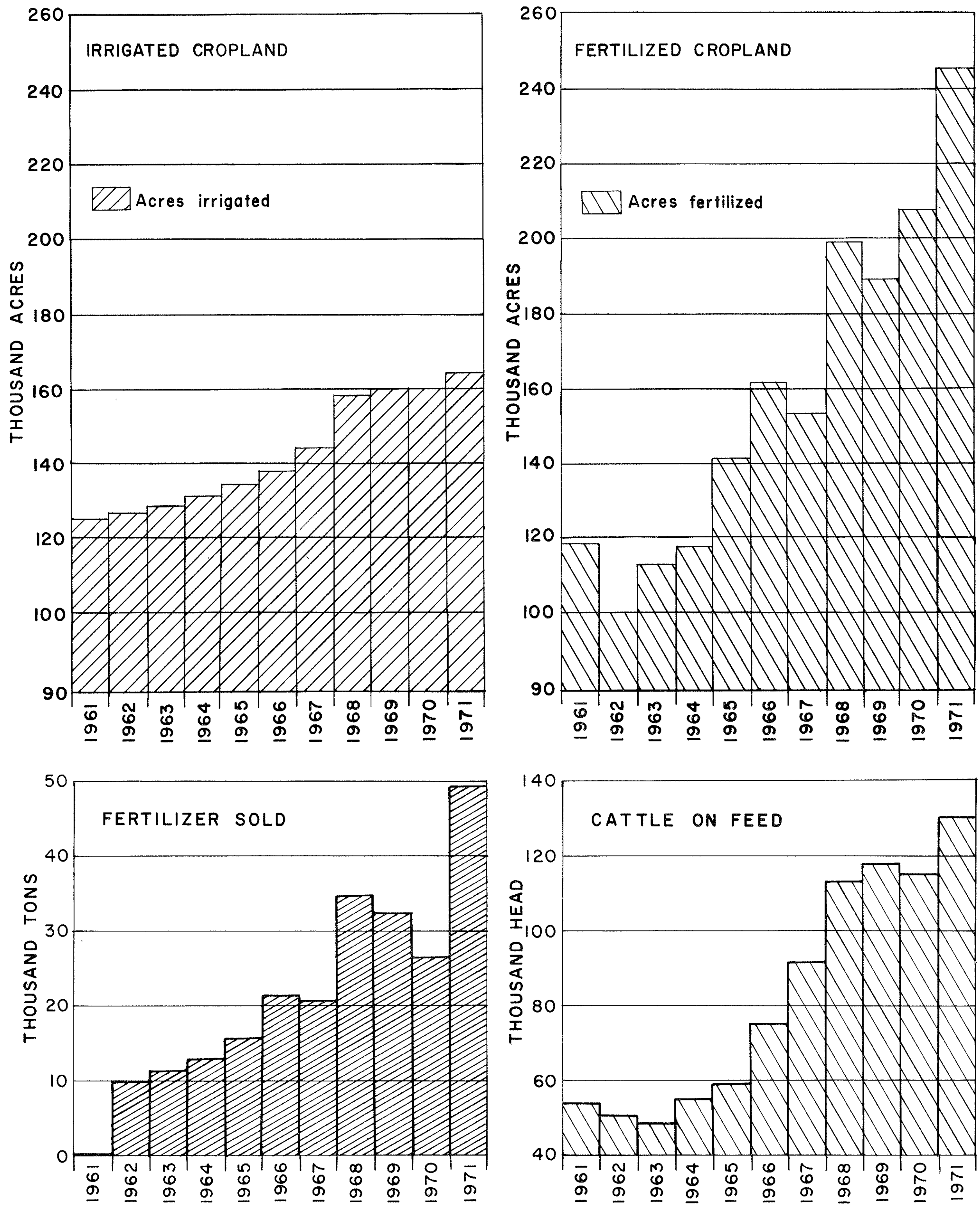

Figure 8.--Acreages of fertilized and irrigated cropland, tonnages of fertilizer sold, and number of cattle on feed, by years, 1961-71.

fertilizer containing phosphate were applied to crops. At present the data necessary to break down the N:P:K (nitrogen: phosphorus: potassium) contents of the dry mixed fertilizer are not available; most farmers questioned indicated that they choose the 7:21:7 dry mix when it is available.

Table 1.--Estimated nitrogen balance for Hall County, 1971

(See Appendix C for assumptions and computations on which values of tons N/yr are based)

NITROGEN GAINS

Source	Tons N/yr	Percent of total for county
Fertilizer:		
Anhydrous NH_3....................	11,546	
Liquid NH_4OH....................	2,727	
NH_4NO_3..........................	717	
Dry mixed.........................	1,502	
Subtotal...........	16,492	65.2
Feedlot manure:		
110,000 cattle..................	6,633	
52,900 pigs.....................	261	
Subtotal...........	6,894	27.3
Domestic waste:		
Septic tanks (14,682 people)....	96	
Community sewage effluent.......	76	
Subtotal...........	172	.7
Precipitation........................	1,725	6.8
Total for county................	25,281	100.0

Table 1.--Estimated nitrogen balance for Hall County, 1971 -- Continued

NITROGEN LOSSES

Sink	Tons produced	Tons N/yr	Percent of total for county
Atmosphere:			
Fertilizer:			
Anhydrous NH_3....................		1,732	
Liquid NH_4OH....................		409	
NH_4NO_3..........................		150	
Feedlot............................		87	
Subtotal...........		2,378	37.0
Runoff:			
NO_3 and NH_4, both as N..............		150	2.3
Crops:			
Irrigated corn.......	3,968,412		
Nonirrigated corn....	8,467		
Irrigated sorghum....	4,193		
Nonirrigated sorghum.	7,160		
Irrigated soybeans...	2,164		
Nonirrigated soybeans	94		
Irrigated alfalfa....	14,850		
Nonirrigated alfalfa.	41,160		
Wheat	12,326		
Oats................	151		
Barley..............	22		
Rye.................	112		
Total.......	4,059,113	~ 7,495	

Table 1.--Estimated nitrogen balance for Hall County, 1971 -- Continued

NITROGEN LOSSES -- Continued		
Sink	Tons N/yr	Percent of total for county
48 percent of N recycled from crops to feedlots................	-3,598	
Subtotal..........	3,897	60.7
Total for county........	6,425	100.0
Excess N (gains minus losses).......	18,863	

Analytical Data Available for Study

Although several geological and hydrological studies of Hall County have been completed, only two water-quality studies (Piskin, 1973; Atkinson, 1973) have been completed in recent years. Both of these were based almost wholly on the analytical results of four sampling programs. The first of these was a U.S. Geological Survey program involving the annual sampling of several wells from 1960-72. Its purpose was to provide data whereby water-quality trends, if any, could be documented. The second, a joint venture of the city of Grand Island and the U.S. Geological Survey, involved monthly sampling of five wells in and near Grand Island during 1971. Its purpose was to demonstrate whether seasonal fluctuations in pollutant concentrations occur. Also in 1971, the Hall County Health Department and the Hall County Cooperative Extension Service collected 322 groundwater samples for nitrate analyses. Completed in the three months from July to September 1971, the fourth sampling program was an effort of the University of Nebraska's Conservation and Survey Division to obtain good areal distribution of water-quality data for Hall County. It involved collecting one sample from each of 91 irrigation, 34 public-supply, 31 domestic, 2 stock, and 3 observation wells--a total of 161 wells. At least 6 to 9 wells were sampled in each township; a larger number was sampled in the township containing Grand Island and in the adjacent township to the west. Also in 1971, one water sample was collected from each of three locations along the Platte River.

Seasonal Variation in Concentrations of Selected Ions

The monthly sampling during 1971 of five wells in and near Grand Island (fig. 9) revealed that concentrations of nitrate and phosphate vary seasonally. Analytical results for this short-term study are given in the appendix (table 1 of Appendix D) and are

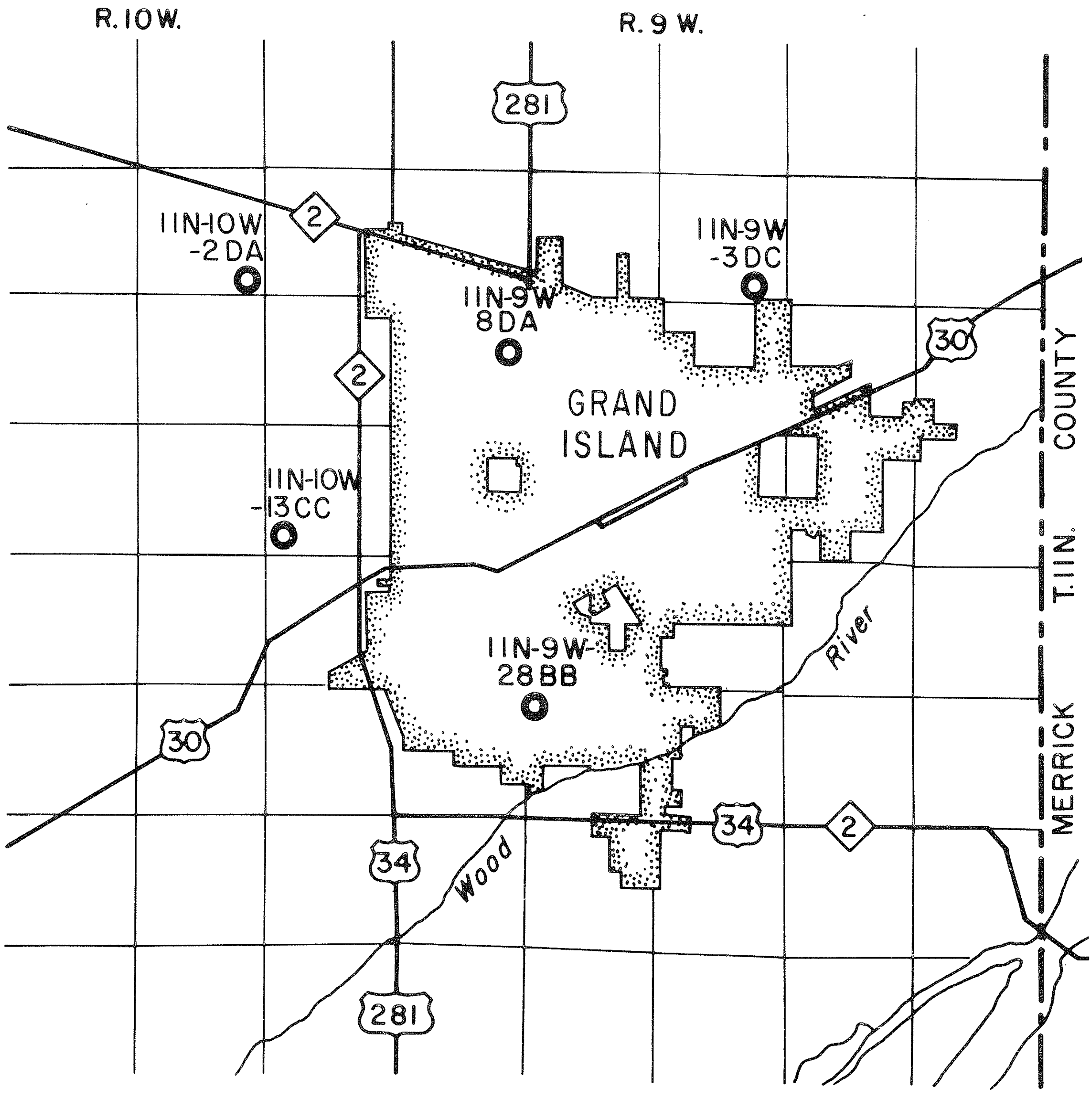

Figure 9.--Locations of five sampled wells in and near Grand Island.

shown graphically in figure 10. The data for nitrate are summarized in the following table:

Table 2.--Average annual concentrations and average seasonal high concentrations of nitrate in water from five wells, 1971.

Well number1/	Average concentration, 1971	Seasonal high nitrate concentration			
		February-March		May-June	
		Average	Departure from annual average	Average	Departure from annual average
	mg/l	mg/l	Percent	mg/l	Percent
11N-9W-3DC...	73.7	79.0	+ 7	85.8	+16
11N-9W-8DA...	26.5	30.8	+16	24.8	- 6
11N-9W-28BB..	27.7	36.0	+30	30.2	+ 9
11N-10W-2DA..	34.3	40.7	+19	36.0	+ 5
11N-10W-13CC.	19.0	26.2	+38	20.0	+ 5

As shown, average February-March concentrations of nitrate ranged from 7 to 38 percent higher than the average annual concentrations. Similarly, all but one of the May-June concentrations were higher than the annual average. During the period

1/ Well numbers are based on the U.S. Bureau of Land Management's survey of Nebraska. The numeral preceding the N (north) indicates the township, the numeral preceding the W (west) indicates the range, and the numeral preceding the terminal letters indicates the section. The terminal letters A, B, C, and D indicate the well's location within the section. The first letter denotes the quarter section, or 160-acre tract, and the second the quarter-quarter section, or 40-acre tract. These letters are assigned in a counterclockwise direction, beginning with A in both the northeast quarter of the section and the northeast quarter-quarter of the quarter section. Where two sampled wells are located in the same quarter-quarter section, an identifying digit is appended to each well number.

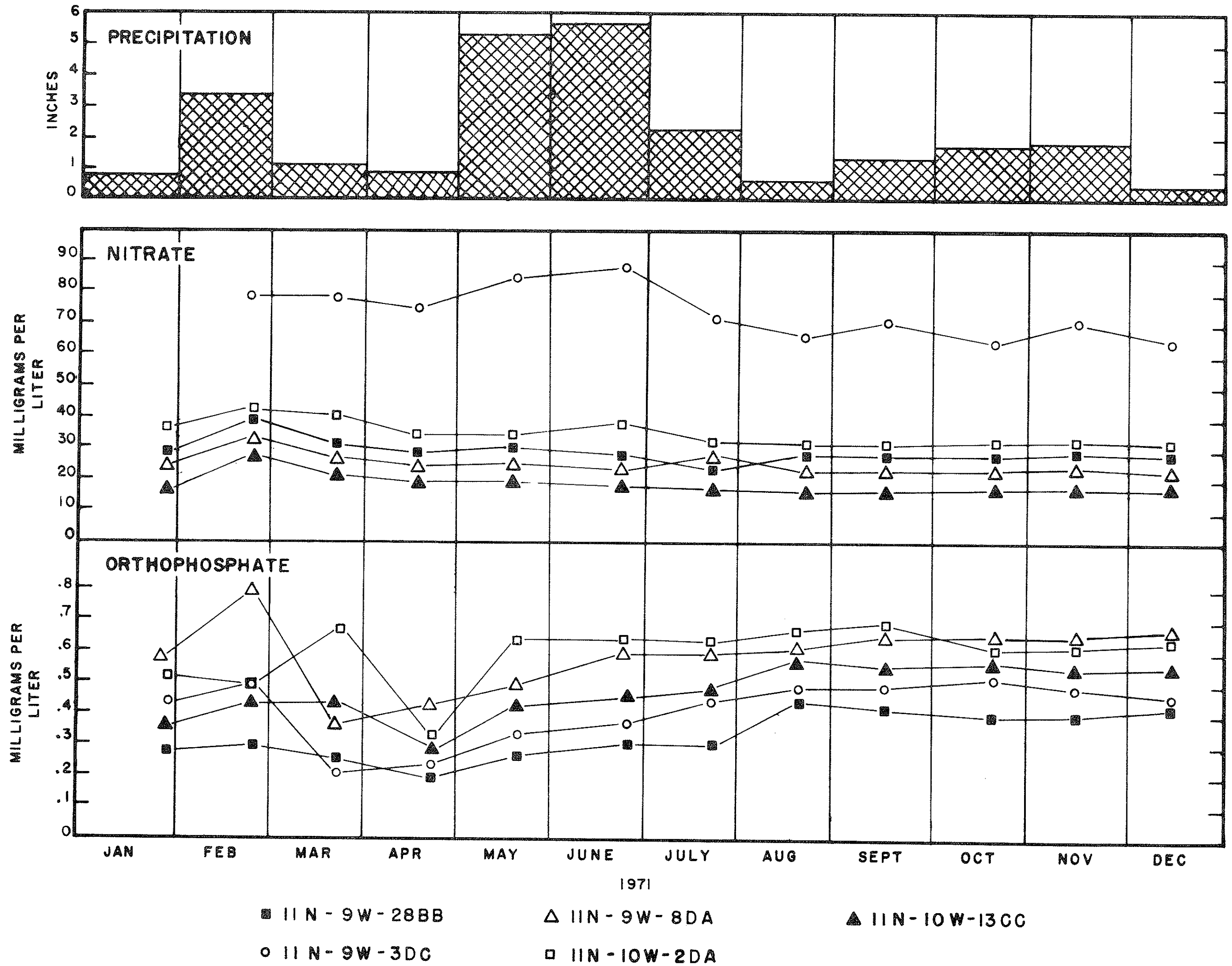

Figure 10.--Monthly precipitation and concentrations of nitrate and orthophosphate in monthly samples of water from five wells in and near Grand Island, 1971.

July through December, concentrations remained relatively stable. Comparison of monthly nitrate concentrations with monthly precipitation amounts (fig. 10) shows that in 1971 the seasonal increases in nitrate concentrations coincided with periods when moisture was more generally available.

Noting rapid depletion of nitrate concentrations in undisturbed soils on which corn was grown, Thomas (1972) concluded that nitrate in moist or wet untilled soils remains mobile and migrates or leaches vertically downward. An analagous situation commonly occurs in Nebraska when the past year's crops form a mulch on the soil and hold nitrate until the transport mechanism, either snowmelt or rain, carries the nitrate into the soil column and eventually into the groundwater. Probably circumstances such as these accounted for the first of the two seasonal nitrate increases that were observed in 1971.

Hedlin (1971) reported that soils under fallow fields in Manitoba, Canada, had higher nitrate concentrations than did soils under fields used for crop production. He noted also that nitrate concentrations in cropped soils were highest in July. In relation to plant growth, July in Manitoba is comparable to late May and early June in Nebraska. Thus it seems likely that the second nitrate increase, which occurred early in the growing season of 1971, was related to the combined factors of high availability of nitrate from freshly applied fertilizer, immaturity of crops, and abundance of moisture.

Phosphate concentrations, unlike nitrate concentrations, were generally highest during the drier months of late summer and fall (fig. 10). It is postulated that the increase may have been related to lack of infiltrating precipitation and to the general decline of the water table. The comparatively wide fluctuations in phosphate concentrations during late winter and early spring may reflect large differences in the amount of snowmelt and precipitation infiltrating to the saturated zone.

Seasonal changes in chloride concentrations were mostly too small to be considered significant.

Timing of the countywide sampling program was somewhat unfortunate in that concentrations of nitrate and phosphate were in the process of stabilizing after a period of fluctuation. Although sampling in the fall probably would have produced data more suitable for a baseline study, it is recognized that the months chosen for the sampling were far more suitable than an earlier period in the year would have been. The statistical method used in this report for presenting the analytical results should minimize any bias that might result from seasonal fluctuations.

Trends in Nitrate Accumulation in Selected Wells, 1960-70.

If all the excess nitrogen from the mass balance of nitrogen supply versus nitrogen loss in Hall County (table 1) is assumed to have entered the groundwater, a resultant increase of about 9.7 mg/l nitrate would be evidenced. This calculation assumes that there is complete dilution of nitrate in an assumed groundwater volume of 9.8×10^{12} liters and that all the nitrogen is in the nitrate form. Although this assumption is not valid chemically and hydrogeochemically, for reasons to be discussed later, it is apparent from figure 11 that substantial increases in nitrate have occurred over the past four years in selected wells from Hall County. For some wells the increase since 1970 appears to be as much as 4 mg/l per year. Figure 8 indicates that during this same period fertilizer sold in Hall County increased dramatically as did the number of cattle on confined feeding. Certainly these sources have the potential to cause increased nitrate accumulation in the groundwater of Hall County.

Transport of Selected Ions from Land Surface to Groundwater

The chemical reactivity of the orthophosphate ion and the nitrate ion differ considerably. Although in Hall County both ions have identical sources--such as fertilizers, animal wastes, sewage, and precipitation--the large differences in their hydrochemistry preclude their transportation with the same efficiency

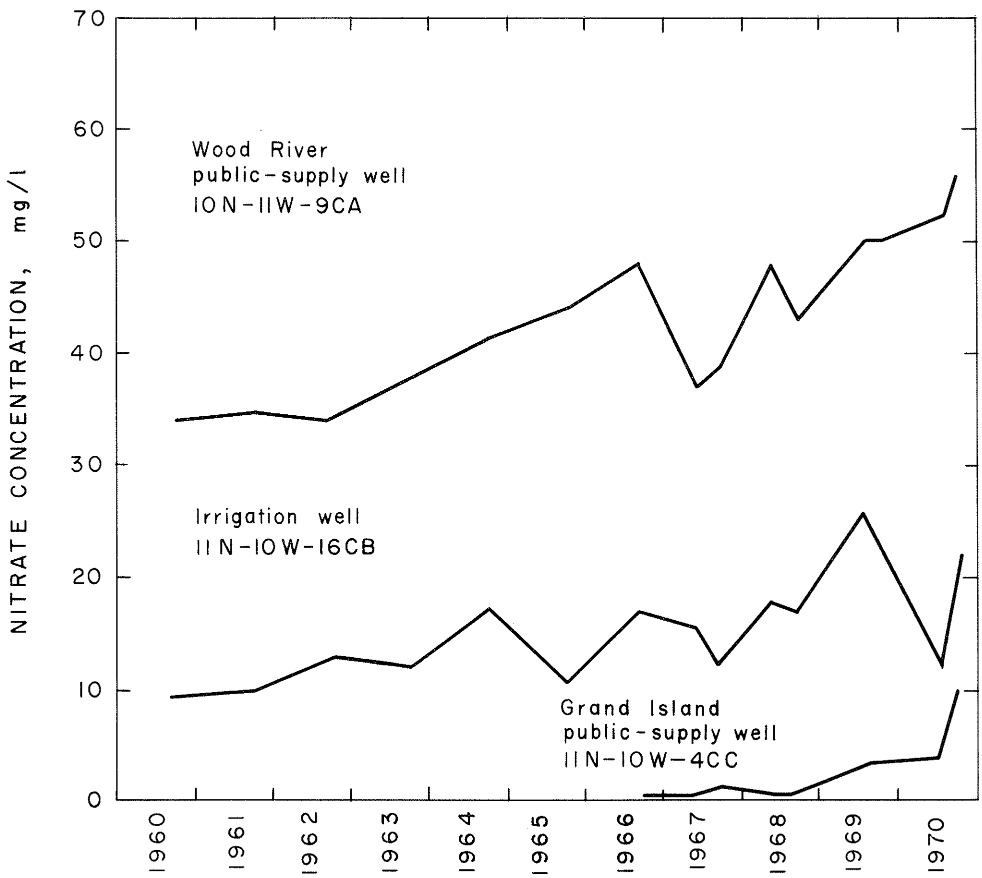

Figure 11.--Concentrations of nitrate in annual samples of water from Wood River public-supply well and two irrigation wells.

into groundwater.

Phosphates form a multitude of low solubility compounds in soils. Chemically, phosphates may react with the ferric ion, the calcium ion, and the aluminum ion with a resultant fixation of the phosphate via precipitation. Phosphates also have a pronounced affinity for clays and have high adsorptivities on montmorillonite, kaolinite, and illite. For this reason phosphates are rarely moved more than a few inches from the point of application (Kurtz, 1970). Many investigators including Taylor (1967), Stanford et al. (1970), Fitzsimmons et al. (1972), and Benoit (1973) have demonstrated that phosphate losses from fertilized land are almost completely in the form of particulate erosion. Thus phosphates in normal oxidized environments are almost totally immobile. Only in anomalous situations such as reducing zones and very sandy soils can phosphate leaching occur. Phosphates have been shown to be mobilized when they are released from ferric phosphate compounds as a result of the reduction of the ferric ion. Hallberg et al. (1972) have reported the apparent solubilization and mobilization of phosphates in reducing sediments. In general, the sand fraction of sediments is inert and will not combine with even immobile ions. Where soils are sandy and the water table is near the land surface, phosphate is likely to be leached into the groundwater. High phosphate in groundwater under conditions similar to the above have been reported by Fitzsimmons et al. (1972). The mechanisms of phosphate transport will be discussed in relation to specific situations in Hall County.

After nitrate is added to the soils, its transport shows neither chemical nor physical similarities to the transport of phosphate. As reported by King (1959), nitrate is exceedingly soluble in water (16.3 g/l). It does not combine with other elements to form insoluble precipitates and is not adsorbed on clay to any extent. Moreover, most soils are negatively charged and therefore repel the negatively charged nitrate ion. Nitrate is thus one of the most easily leached ions. Apparently, however, it is not totally free to migrate, for Thomas (1972) reported that in no case is the distribution coefficient of nitrate between soil and water zero. This indicates that nitrate is held to some extent by soils, even though it is much more readily leached than most anions.

Thomas and Swoboda (1970) demonstrated a similar negative adsorption effect for chloride, an anion similar to nitrate. The effect of negative adsorption is a longer pathway between land surface and water table for negatively charged chloride and nitrate ions than for positively charged ions. Thus certain interstitial channels become resistant to chloride inclusion, whereas other larger and less charged pores permit chloride mobility. In summation, total nitrate transport is thought to be similar to chloride transport in pore water and likewise is dependent to some extent on soil type. Where soils contain large percentages of sand, this hypothesis is invalid and total mobilization is thought to occur.

Within soils, nitrate can be reduced to nitrite, to nitrogen dioxides, and finally to nitrogen. This pathway is called destructive denitrification and ultimately releases the nitrogen from the soil to the atmosphere. The form that the compounds assume in soil is dependent on the bacteria present and on the redox potential (available oxygen) of both the soil and the pore water. Because nitrogen is a gas, it is evolved from the soil under certain bacterial conditions and the atmosphere becomes an infinite sink. This is shown clearly in the nitrogen mass balance (table 1) for Hall County.

Evolution of nitrogen followed by loss to the atmosphere is the result of two different processes. One is volatization of ammonia, which occurs on the soil surface directly after anhydrous ammonia application; the other is denitrification, which is due to biological reduction of nitrate to nitrite and nitrogen. Ammonia, the most reduced form of nitrogen, may also escape to the atmosphere via biological denitrification. However, from 0° to 40°C and at a pH of 7.0 more than 95 percent of the ammonia is in solution in the ionized form (NH_4^+) and probably is rapidly exchanged with the soil. Kurtz (1970) has reported that in aerobic (oxidizing) soils, applied ammonia is converted to nitrite by bacteria called Nitrosomonas and further oxidized to nitrate by Nitrobacter. This process of nitrification generally takes a few weeks. Nitrification is a constructive process which allows conversion of amino acids and ammonia to the readily available nitrate ion. Plants then take up nitrate and convert it to amino acid. This is called constructive denitrification. A further complication described by Allison (1965) is concerned with estimation of absorption of nitrate by crops. He points out that high nitrate concentrations occur initially in plants, followed by progressively lower nitrate concentrations as the crop matures; therefore, denitrification along with the dilution that accompanies increased crop weight appears to be taking place within the plants. The estimates given in table 1 for nitrogen losses due to plant denitrification and plant absorption result from calculations shown in Appendix C-2.

The combined effects described above make extremely difficult the estimating of total nitrate available for transport to groundwater. Use of an N^{15}/N^{14} tracer would result in better estimates but, for the present, gross trends can be used to indicate locations in Hall County where leaching of nitrate is causing significant groundwater pollution. In places where both nitrate and phosphate concentrations are anomalously high, rapid infiltration to groundwater is likely to be occurring.

Sources of high concentrations of sulfate in Hall County are also difficult to assess. High concentrations in groundwater can be a result of natural sulfate from river seepage or leaching of gypsum within the soils. Because many Hall County soils are naturally gypsiferous, it is impracticable to use sulfate concentrations in groundwater as an indicator of pollution.

In some instances, concentrations of chloride are useful indicators of sources of nitrate in groundwater. Potassium chloride in fertilizer and chloride in manure are important sources of chloride in soils, and some of the chloride from these sources is depleted to groundwater. However, use of potash in Hall

County is not extensive because the soils are naturally high in potassium. It is estimated that concentrations of chloride derived from infiltrating rainwater are about as great as concentrations derived from fertilizer and that chloride from both sources does not add significantly to the total chloride concentration of the soil. Furthermore, chloride is taken up by plants to a considerable extent (Goodhall and Gregory, 1947). Thus soils probably do not contribute much chloride to groundwater in Hall County, and anomalies that do occur are most likely due to leaching from feedlot wastes and septic tanks. Duffer et al. (1971) reported that feedlot wastes are known to have caused increases in chloride concentration of more than 25 mg/l. The high concentrations of both nitrate and chloride in water from well 11N-9W-3DC are regarded as indicators of pollution from feedlot wastes or septic tanks.

Dispersion of Ions in Groundwater

All constituents of groundwater tend to become more widely and uniformly dispersed with time. Factors involved in dispersion are groundwater movement in response to the hydraulic gradient, advection currents caused by spatial differences in water density, and molecular diffusion resulting from spatial differences in concentration of the constituent.

The rate of dispersion from a point source can be calculated from the formula $D = \alpha V/\phi$, where D is the dispersion coefficient, α the coefficient of dispersivity, V the velocity of flow, and ϕ the porosity. Substitution of 200 feet for α (Robson, 1973), 3 feet per day for V, and 0.35 for ϕ gives 626,000 square feet per year for the area throughout which a given constituent would be dispersed in a saturated porous medium. This value, equivalent to 14 acres, should be regarded as a gross estimate of the annual increment to the areal extent of a groundwater plume of high nitrate, high chloride, or some other excess constituent derived from a point source.

To the author's knowledge, no formula for the dispersion of a solute from a continuously supplying line source has appeared in any publication. Presumably, the spread of any such solute advances as a linear front that approximately parallels the source. In the case of the Platte River as a line source, groundwater movement and advection are believed to overshadow molecular diffusion as factors controlling dispersion.

As shown by the flow lines in figure 3, seepage from the Platte River moves away from the river at angles ranging from about 10 to 30 degrees in a horizontal plane. Such movement, however, results only in lateral dispersion.

To account for vertical dispersion in conjunction with lateral dispersion, it is suggested here that "stirring" also occurs. Advection, a more precise term for the stirring effect, is the movement within a large body of water of smaller bodies of water having different densities. The existence of these smaller bodies of water is postulated because of temperature differences between water in the line source and water in the aquifer. Temperature of seepage from the Platte River varies seasonally, whereas the temperature of water already in the aquifer is nearly constant. Thus, because river water is colder in winter than groundwater, seepage from the river tends to sink and move along the base of the aquifer. Contrariwise, because river water is warmer in summer than groundwater, seepage tends to remain at and move along the top of the aquifer. The amount of "stirring" that results from the existence of these bodies of different temperatures diminishes with distance from the river and uniformity of water temperature is ultimately achieved. This homogeneity in water temperature may be accelerated as a result of increased pumping away from the river. Furthermore, with increasing distance from the river, an increasing percentage of the groundwater is derived from infiltrating precipitation. It is believed that the observed banding of chloride concentrations in bottomland groundwater could be established within as short as time as twenty years under the existing hydraulic regime.

To prove or disprove the advection hypothesis, it is proposed that a detailed investigation of depth differences in water temperature and water quality be made in the vicinity of the Platte River. This would involve the installation of a series of specially designed wells along lines extending away from the river. Screened at selected depths within the aquifer, these wells should be instrumented so that the desired determinations could be made reliably. Until pertinent data are obtained experimentally, modeling of pollution transport within the groundwater can not be accomplished.

Areal Distribution of Selected Water-Quality Parameters

The remaining discussion of groundwater quality is based principally on analytical data from the countywide sampling program of July, August, and September in 1971. These data form the exclusive basis for the following considerations of ions whose concentrations are known to be changing with time. For considerations of other ions, appropriate data from the sampling programs made to determine long-term trends and seasonal changes in water quality are used also.

Analytical methods.--Both temperature and pH of the samples were measured on location. Temperature was measured with a thermometer and pH was determined by the Hach phenol red method. The specific electric conductance was measured with a solu-bridge. Laboratory analyses for nitrate, sulfate, phosphate, and chloride were made using Hach kit methods and a Hach AC-DC direct-reading colorimeter. All samples were collected and stored in plastic bottles, but no standard precautions were made for the storage of nutrient (phosphate and nitrate) samples. These precautions are strongly advised in _Standard Methods for the Examination of Water and Wastewater_ (Am. Public Health Assoc., 1965). Some samples were stored at room temperature for as long as four months.

For nitrate determinations, the cadmium reduction method with 1, naphthylamine-sulfanilic acid was used. This test measures both nitrate and nitrite-nitrogen. Phosphate analyses were conducted by the molybdenum blue method using stannous reductase. Sulfate determinations were made by a modification of the barium sulfate turbidimetric method, and chloride analyses were made by the mercuric nitrate method. All analyses were done on unfiltered samples; therefore, the results represent both dissolved and particulate ions.

Analytical results.--The results of 161 groundwater analyses from Hall County are listed by well number in table 2 of Appendix D. Nitrate concentrations given in this table range from a trace to 108 mg/l and average 14 mg/l. Water from 13 percent of the wells had nitrate-nitrogen concentrations greater than 10 mg/l. Total orthophosphate concentrations ranged from a trace to 1.7 mg/l and averaged 0.25 mg/l. The majority of samples (76 percent) had orthophosphate concentrations less than 0.20 mg/l and only 20 percent had concentrations greater than 0.40 mg/l. A range encompassing three orders of magnitude was observed for sulfate concentrations, the concentrations ranging from 1 to 1,200 mg/l and averaging about 150 mg/l. Twenty-five percent of the samples had sulfate concentrations greater than 250 mg/l. Chloride concentrations were relatively low, ranging from 1.3 to 55 mg/l and averaging 15 mg/l. The pH ranged from 6.6 to 8.1 and averaged close to neutrality (7.0). Specific conductance ranged from 203 to 1,970 micromhos per centimeter.

Zones of differing ionic concentrations in groundwater.--The chemical data for groundwater in Hall County provide a basis for defining water-quality zones, each of which is characterized by its average specific conductance or average concentration of a specific ion. These zones, shown on a series of maps (figs. 12 through 16), are distinguished by different colors--dark red, red, pink, dark gray, light gray, and white (in order of decreasing average values). For most zones, the average value and the value of one standard deviation are indicated numerically, along with the number (n) of samples analyzed. This method of depiction assumes a

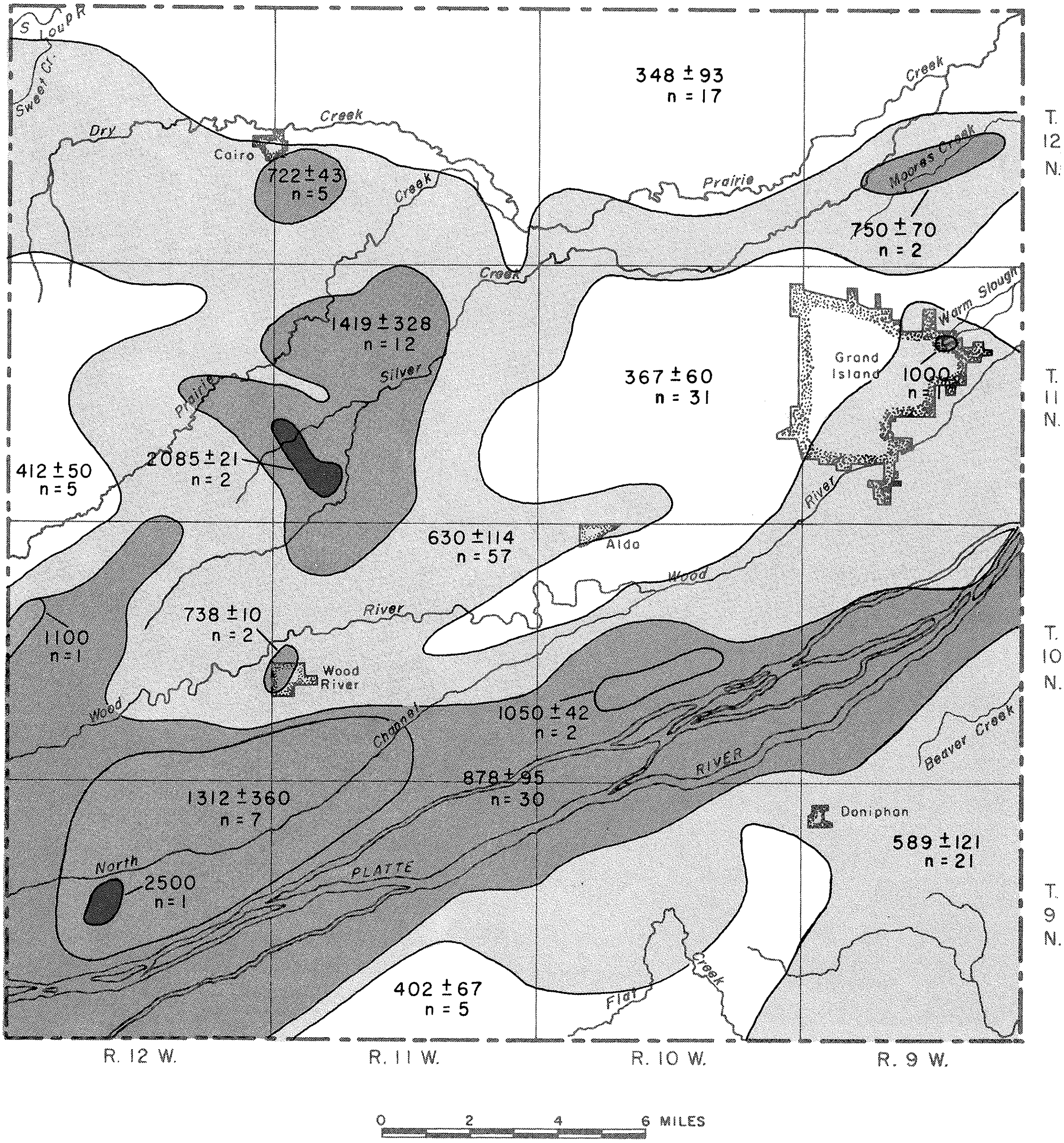

Figure 12.--Distribution of specific conductance values for groundwater, 1971. Shown for each zone is the average specific conductance (micromhos at 25 C) ± one standard deviation, based on n, the number of samples analyzed.

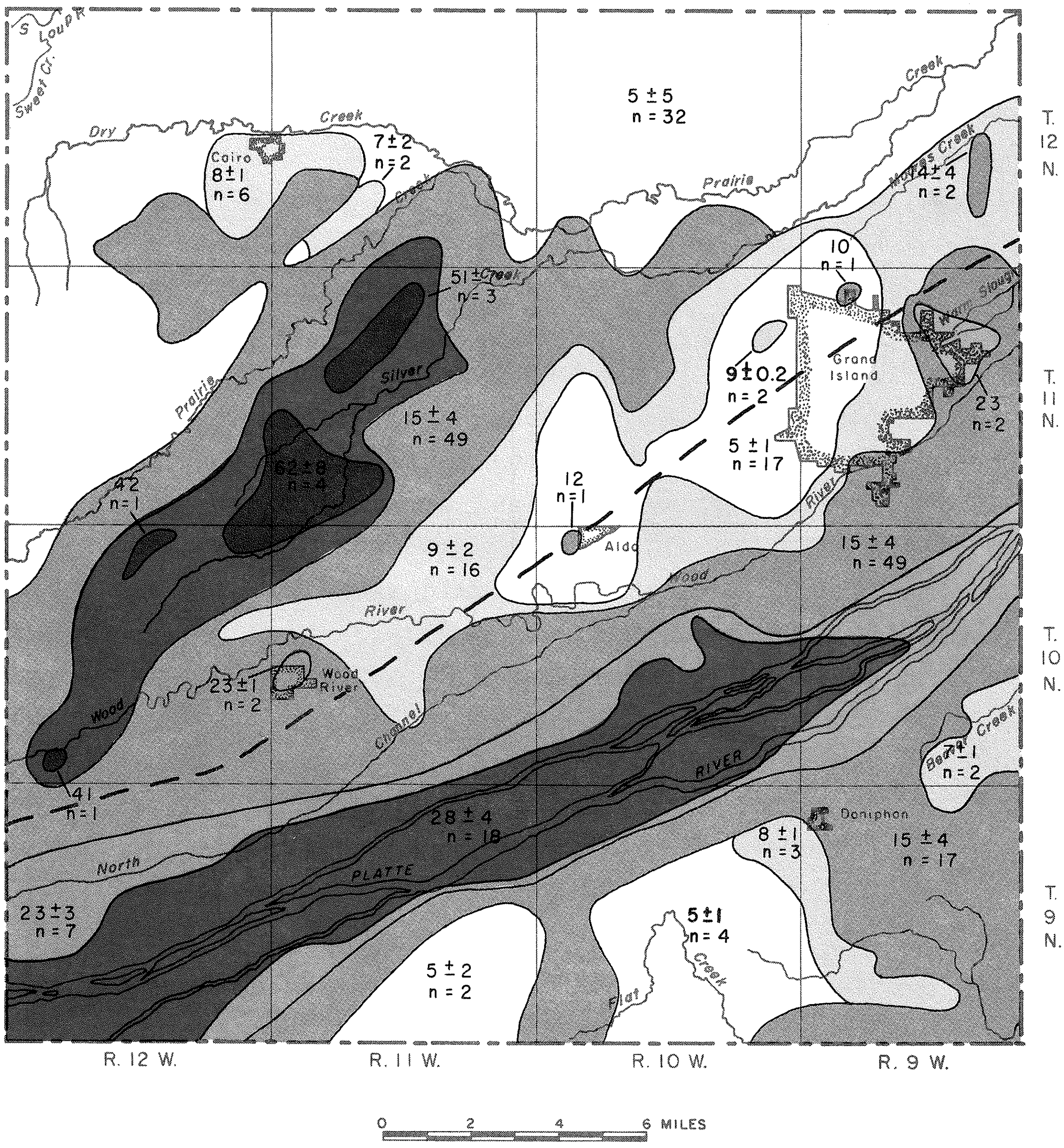

Figure 13.--Distribution of chloride in groundwater, 1971. Shown for each zone is the average chloride concentration (mg/l) ± one standard deviation, based on n, the number of samples analyzed. The heavy dashed line represents the approximate northern limit of influence of seepage from the Platte River.

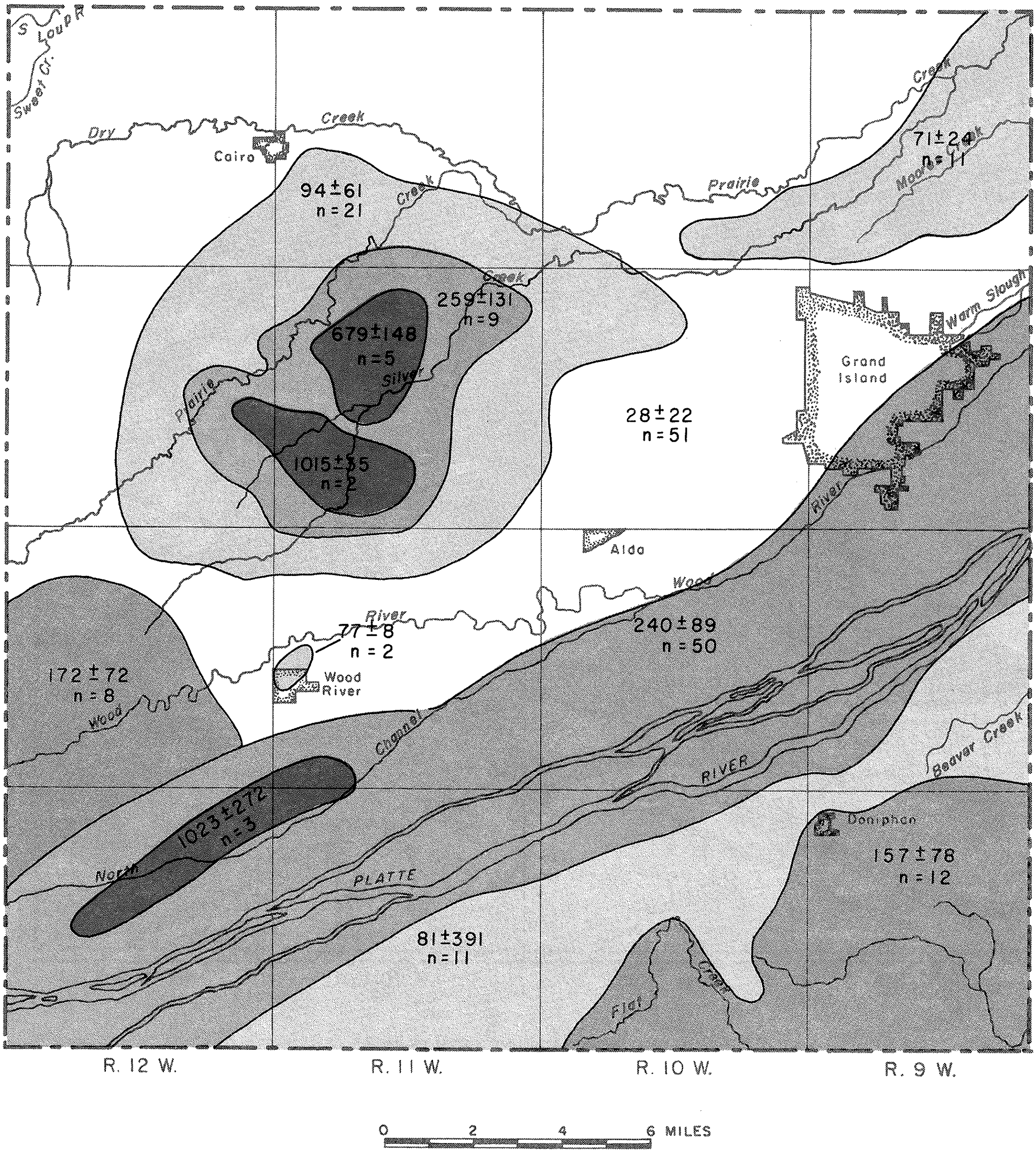

Figure 14.--Distribution of sulfate in groundwater, 1971. Shown for each zone is the average sulfate concentration (mg/l) ± one standard deviation, based on n, the number of samples analyzed.

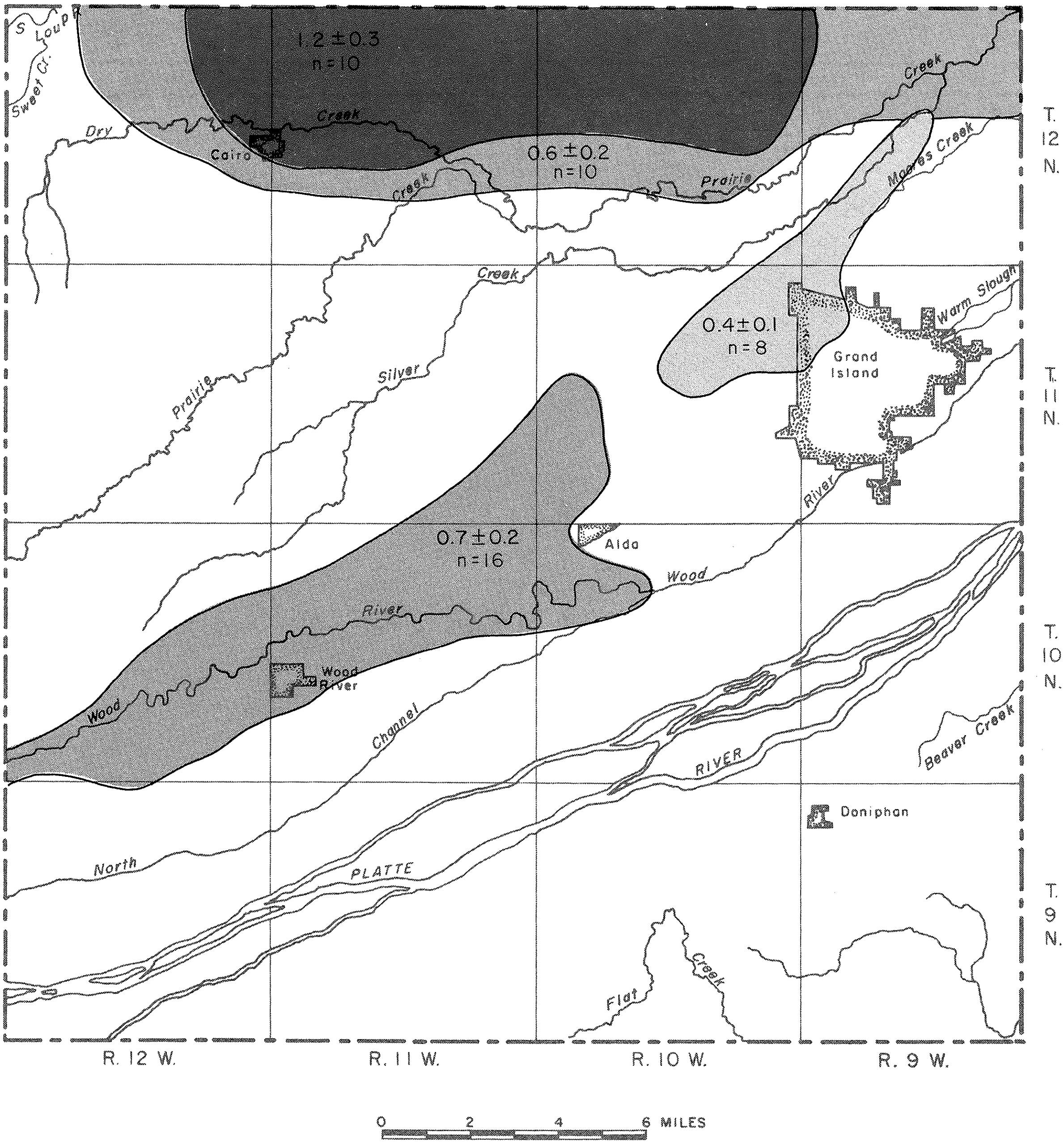

Figure 15.--Distribution of phosphate in groundwater, 1971. Shown for each zone is the average phosphate concentration (mg/l) ± one standard deviation, based on n, the number of samples analyzed. Blank areas average less than 0.1 mg/l phosphate.

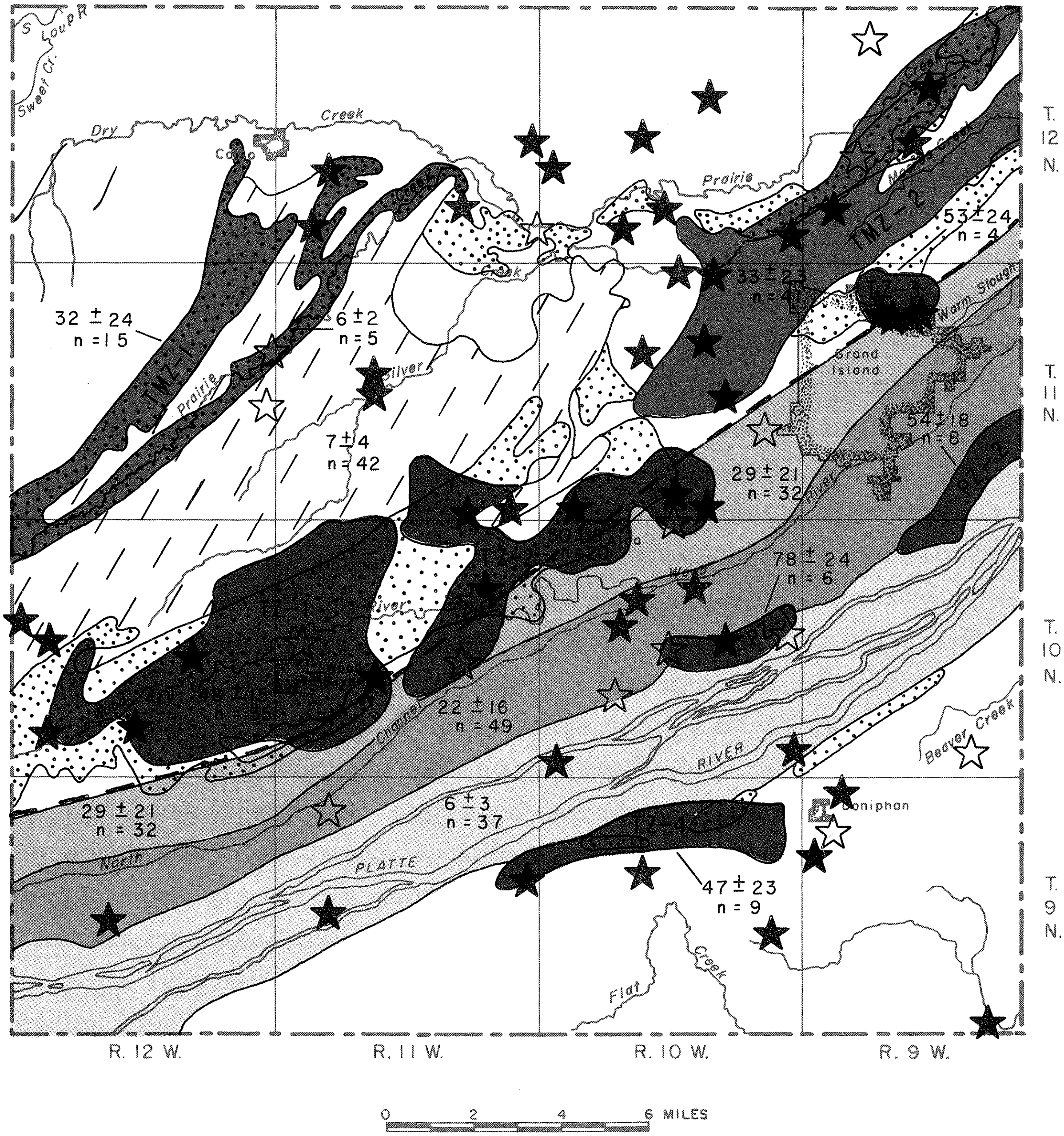

Figure 16.--Distribution of nitrate in groundwater, 1971. Shown for each zone is the average nitrate concentration (mg/l) ± one standard deviation, based on n, the number of samples analyzed. Average nitrate concentration for white area north of Platte River is <10mg/l, for white area south of Platte River <20mg/l. Black stars represent active feedlots, white stars abandoned feedlots. Dotted areas are Hord-Hall soils, dashed areas Wood River soils. The heavy dashed line represents northern limit of influence of seepage from Platte River.

normal distribution of values and gives the upper and lower boundaries of the range that encompasses about two-thirds (actually 68.26 percent) of the values nearest the average value for the zone. For example, the designation "589±121, n=21" near the lower right-hand corner of figure 12 indicates that the average specific conductance of the 21 samples analyzed was 589 micromhos and that 68 percent of the analytical values fell within 121 micromhos (one standard deviation) above and below that average value. Obviously, the greater the number of analytical values, the greater the significance of the standard deviation. The purpose of approaching the data with this method is to reduce bias resulting from slight seasonal changes in concentrations during the sampling period, from possible sampling or analytical errors, and from undue effects of poorly constructed wells that may have permitted direct surface water contamination of the aquifer.

Only a brief discussion seems necessary for the properties of temperature, pH, and specific conductance. Water temperatures for 75 wells (46 irrigation, 27 public-supply, 1 stock, and 1 observation) in Hall County average 12.2°C (52.9°F). In general, water in wells near the Platte River in western Hall County was slightly cooler than elsewhere; however, the small sampling size limits further interpretation of the temperature data. The pH of all samples was nearly the same and close to neutrality. Specific conductances differed considerably, the highest concentrations occurring in the bottomland along the Platte River and in a terrace area between Cairo and Wood River (fig. 12). In general, values of specific conductance serve as an approximate measure of the concentration of dissolved solids, although the correlation of one to the other is less than perfect. In bicarbonate waters, the amount of dissolved solids in milligrams per liter commonly is about 65 percent of the specific conductance in micromhos. However, values of specific conductance afford no clues as to which ions are significant contributors to the dissolved solid concentration. Obviously, specific chemical analyses are better suited to that purpose.

The following discussion of areal distributions and probable sources of selected chemical constituents in Hall County groundwater is based on analyses for chloride, sulfate, phosphate, and nitrate. The distributions of zones of differing concentrations of these chemical constituents are shown in figures 13, 14, 15, and 16. Those characterizing the bottomland along the Platte River are considered first. This part of the county is an area in which soils and underlying saturated material consist mostly of moderately to highly permeable sediments that generally are well drained except where the water table is near the surface. Sand is the predominant constituent of both the soil and the unsaturated zone beneath it; clay layers are mostly thin and discontinuous. With only a few exceptions, groundwater beneath the bottomland is characterized by relatively high chloride and sulfate and relatively low phosphate and nitrate.

The zone of highest average chloride concentrations in groundwater is immediately adjacent to the river, and bordering both sides of this zone are bands of lower average chloride concentrations (fig. 13). Three analyses of Platte River water indicated an average chloride concentration of 26 mg/l, which is almost precisely the concentration of chloride in groundwater close to the river. The banding of decreasing chloride concentration away from the river seems to indicate that seepage from the river is the principal source of groundwater near the river and that dilution occurs with increasing distance from the river. Groundwater beneath the bottomland farthest north from the river has about 50 percent less chloride. This appears to mean that for every liter of Platte River water in the aquifer at the north margin of the bottomland there is one liter of water from another source, presumably precipitation. Inland precipitation on the average has less than 1 mg/l chloride (Gambell and Fisher, 1966) Thus the chloride flux from precipitation can be considered negligible.

Another hypothesis is that the high chloride concentrations close to the Platte River come from dissolution of evaporites within the soil horizons. Yost et al. (1962) report that capillary action where the water table is high results in the formation of white salt crusts on several of the bottomland soils and that these salts later are leached downward by infiltrating precipitation. However, J. A. Elder (personal communication) indicates that the leaching of such deposits probably causes only slight seasonal fluctuations in the chloride concentration of the groundwater and does not greatly affect the average groundwater concentration. It appears, therefore, that the chloride concentrations in groundwater beneath the bottomland are controlled by seepage from the Platte River and dilution by infiltrating precipitation.

As shown by figure 14, the average sulfate concentration in the groundwater beneath the bottomland is only a little lower than the 250 mg/l limit set by the U.S. Public Health Service (1962). This high concentration appears to be related to infiltration of Platte River water, samples of which also contained about 250 mg/l. Drinking water having such a high concentration of sulfate may have a slight diarrheic effect on people, particularly those accustomed to water of lower sulfate content.

Water from two wells in the southwestern part of the bottomland contained significantly higher sulfate concentrations. These seemingly local occurrences of high sulfate concentration in groundwater are not readily explained, but it appears likely that they are related to gypsum evaporite deposits in the soil. Although none of the bottomland soils is described by Yost et al. (1962) as including gypsiferous layers, gypsum must be present in the soil at least in those places where surficial salt crusts indicate that groundwater is being raised to the land surface by capillary action. This is a reasonable conclusion because, as already pointed out, the groundwater has a moderately high sulfate content throughout the bottomland area. It is hypothesized that precipitation infiltrating the salt-encrusted soils adds sulfate to groundwater that already is moderately high in sulfate and eventually results in local bodies of groundwater excessively high in sulfate.

The solubility product (K_{sp}) of calcium sulfate at 25°C is 2.4×10^{-5} moles/liter (King, 1959); therefore, the maximum concentration in groundwater would be 0.47 g/l, or 470 mg/l, if solubility were the only factor affecting concentration. However, according to Hem (1970), as much as 1,800 mg/l sulfate is found in conjunction with concentrations of 2,500 mg/l chloride and sodium. Thus the solubility of gypsum is greatly influenced by increased total ionic strength. Moreover, sulfate can form ion pairs ($CaSO_4^0$) that increase the concentration of total sulfate present. Thus high concentrations of sulfate (more than 500 mg/l) in groundwater are strongly dependent on complex and ion pair formation.

Where shallow groundwater is characterized by relatively low chloride concentrations, gypsum solubility may be the main process controlling sulfate concentration. Therefore, zones of high sulfate (more than 1,000 mg/l) in groundwater beneath the bottomland necessarily would be of small extent. This hypothesis is based on the assumption that the source of sulfate is limited and that sulfate dispersion ordinarily is restricted to the direction of groundwater flow. However, pumping in the immediate vicinity of a zone of high sulfate concentration would divert water from the normal path of movement and thereby accelerate the dissolution process.

Phosphate concentrations in groundwater beneath the bottomland generally were less than 0.1 mg/l (fig. 15). Apparently phosphate concentrations in groundwater do not reflect those in the Platte River, inasmuch as three widely spaced samples collected from the river in August 1971 had total phosphate concentrations that averaged 0.5 mg/l. The river samples were analyzed for total phosphate and, therefore, the analytical results do not represent the true concentrations of dissolved orthophosphate in the Platte River in Hall County. In 1971, dissolved phosphate analyses for the Platte River at Overton (U.S. Geol. Survey, 1973) averaged 0.24 mg/l, which is a more reasonable value in light of the groundwater phosphate concentration. It is suggested that biological uptake, adsorption, and precipitation account for removal of much of the phosphate from the river water as the seepage water recharges the groundwater reservoir. The high surface activity of soluble phosphate makes this suggestion plausible.

Figure 16 summarizes the analytical data for nitrate in groundwater. As shown, the average concentration adjacent to the Platte River was 5.5 mg/l. Between this area and the north margin of the bottomland is a zone in which the average nitrate concentration is significantly greater. Analyses for nitrate in water from 49 wells in this zone indicated an average concentration of 21.5 mg/l. This greater nitrate concentration is further evidence that with increased distance from the river the groundwater contains less river seepage and more infiltrate from the land surface. Analyses for nitrate in the river water at the three sampled locations indicated an average concentration of slightly less than 5 mg/l, which is nearly the same as the average nitrate concentration in the adjacent groundwater. With increased intensity of agriculture toward the north margin of the bottomland, infiltrating precipitation and irrigation seepage transport nitrate from the surface to the shallow water table. Fertilizer appears to be the principal source of the nitrate that is leached downward through the moderately to highly permeable soil materials. If not for the diluting effect of seepage from the Platte River, the nitrate concentration of the groundwater in this zone probably would be significantly higher.

Two small zones of high nitrate concentrations in the groundwater occur in the eastern part of the bottomland. In one, labeled PZ-1, the average nitrate concentration of water from six wells was 78 mg/l and in the other, labeled PZ-2, the average nitrate concentration of water from eight wells was 54 mg/l. Leachate from two abandoned feedlots (white stars) and one active feedlot (black star) is a possible source of the high nitrate concentration in PZ-1, but no such obvious likely source exists for the high nitrate concentration in PZ-2. Since feedlots are generally surrounded by extensive irrigated corn acreages, leachate from the heavily fertilized soil could also account for some of the excess nitrate in the groundwater. From the gross chemical data it is impossible to determine which source predominates in PZ-1; however, the static water level is so close to the land surface that at times the water table may rise to parts of existing feedlot pens and flush waste products directly to the groundwater. Higher chlorides in this zone add weight to this hypothesis. Both zones are in highly to moderately permeable soils and are probably permitting extensive nitrogen transport to the groundwater from fertilizers.

Manure packs in abandoned feedlots are known to contribute nitrate to underlying sediments. For example, Mielke and Ellis (1973) reported nitrate levels as high as 8.5 tons of nitrate-nitrogen per acre at a depth of 45 feet beneath an abandoned feedlot. Apparently manure packs oxidize with time, releasing nitrate for downward transport by infiltrating water. Infiltration of the manure pack and underlying packed soil is facilitated by the increased permeability that results from a combination of freezing and thawing in winter and continued nonuse of the lot.

Whether nitrate leaching occurs in active feedlots has been a controversial subject for several years. Elliott _et al._ (1973), Elliott and McCalla (1973), and Mielke (1973) concluded that a manure pack on a continuously operated feedlot forms an effective barrier to leaching of nitrogen-containing components. Duffer _et al._ (1971) report evidence that nitrogen contamination of surface water from active feedlots generally is in the ammonia form, indicating predominance of reducing conditions. The data indicate that occupied feedlot nitrogen would be in the reduced state and relatively immobile to downward movement, the major exception being in areas where the static groundwater level is in direct contact with the manure pack or feedlot lagoon. This exception, plus the fact that extensive corn agriculture exists near feedlots, may account for the following observations by various researchers.

Deutsch (1963), Smith (1965), Keller and Smith (1967), Stewart _et al._ (1967), Engberg (1967), and Gilham and Webber (1969) have shown indirectly that nitrate concentrations are anomalously high in the groundwater beneath or downgradient from some feedlots.

The available information seems to indicate that abandoned feedlots are much greater contributors of contaminants to the groundwater than are active feedlots. However, in some places soil moisture, oxidizing conditions, and ease of infiltration may be such that active feedlots also contribute contaminants.

In summation, the chemical quality of groundwater beneath the bottomland reflects, in general, the influence of seepage from the Platte River. The Platte River appears to be a source of high chloride, high sulfate, low phosphate, and low nitrate water for this area. If, as has been estimated, river water is moving into the groundwater reservoir north of the river at a rate of 50,000 acre-feet per year, the amount of water added in 20 years is about 1 million acre-feet, or about 60 percent of the estimated total quantity of groundwater beneath the bottomland. Because a reasonable estimate for recharge from precipitation during a 20-year period would account for the remaining 40 percent, it is assumed that the ratio of 1:0.7 represents the approximate proportion of river seepage to infiltrate from precipitation in the bottomland aquifer at any given time. The validity of this assumption is borne out by the following two illustrations.

If river seepage were not a factor, agricultural practices on the bottomland adjacent to the terrace would have caused the average nitrate concentration of groundwater to be about 50 mg/l, the same as that beneath similarly permeable soils on the terrace. Instead, it is 21.5 mg/l, or nearly the concentration of 23.5 mg/l that would result from mixing 1 liter of river water containing 5 mg/l nitrate with 0.7 liter of groundwater containing 50 mg/l.

Again if river seepage were not a factor, groundwater beneath the bottomland probably would have an average chloride concentration of about 5 mg/l, or the same as the minimal observed average concentration in groundwater beneath the terrace. Mixing 0.7 liter of water having that concentration of chloride with 1 liter of river water having 27 mg/l would result in a chloride concentration of 17 mg/l, a value that compares favorably with the observed average concentration of 15 mg/l.

Groundwater beneath the broad terrace north of the bottomland also is characterized by different water-quality zones. Here, however, seepage from the river has only a minor effect on water quality. Its influence is not detectable in water beneath the area north of the heavy dashed line in figures 13 and 16. South of that line, the effect of seepage from the river is so slight that local influences tend to obscure it.

As shown by figure 13, a large zone of higher chloride concentrations extends northeastward from the southwestern part of T. 10 N., R. 12 W., to the south-central part of T. 12 N., R. 11 W. The average concentration of chloride in the greater part of this zone is about 30 mg/l, but in several small areas within the zone the average concentrations are significantly greater. The greatest average chloride concentration (61.5 mg/l) is in the centrally located area about midway between the towns of Wood River and Cairo.

The boundaries of the Wood River soil association (fig. 6) and the zone of high chloride concentration so nearly coincide that the soils logically are suspected to be the principal source of the chloride. Significantly, Yost et al. (1962) reported that subsoils in this association contain saline layers. Considering the long-time relationship of soils to groundwater, one might wonder why the high chloride zone has not expanded more in the direction of groundwater movement. However, as J. A. Elder (personal communication) theorizes, it may be that dissolution of the salt was negligible until accelerated by infiltrating irrigation water. Two east-extending plumes may be evidence that the zone of high chloride groundwater actually is expanding in the direction of groundwater movement.

Two isolated small plumes of chloride-enriched water were revealed by the water-sampling program. One is beneath the town of Wood River and the other is beneath the northeastern part of Grand Island. Both probably result from seepage of treated sewage, in part from septic tanks and in part from disposal ponds.

The general prevalence of low chloride groundwater beneath the terrace indicates that the pre-irrigation chloride concentration probably was nowhere greater than about 20 mg/l. In 1971, the maximum observed concentration was 70 mg/l, which still is far less than the recommended limit of 250 mg/l for drinking water.

Excessively high concentrations of sulfate occur in T. 11 N., R. 11 W. (fig. 14), in approximately the same areas as the highest concentrations of chlorides. As appears to be the case with chloride, soluble minerals in the subsoil of the Wood River soil association are a likely source of the sulfate. Furthermore, it seems plausible that seepage of irrigation water has accelerated the dissolution of gypsum from the subsoil. Sulfate concentrations in water from several wells were two to four times greater than the recommended 250 mg/l for drinking water. Elsewhere the sulfate concentration in groundwater beneath the terrace is generally less than 100 mg/l and in many places is less than 50 mg/l.

A publication of the U.S. Department of Health, Education, and Welfare (1964, p.310) reports that the phosphate concentration in natural waters seldom exceeds 0.3 mg/l. In Hall County, however, concentrations greater than this characterized water from wells on the terrace (fig. 15). Most of these concentrations appear to be related to occurrences of the Hord-Hall and Valentine-Thurman associations. Soils in these associations are extremely low or lacking in calcium carbonate, have a relatively low pH, and have moderate or low clay content. From a chemical standpoint, it seems reasonable that the higher phosphate concentrations are related to these soil characteristics. The American Water Works Association's Water Quality Division Committee on Nutrients in Water (1970) states that at a level of 10^{-3} M Ca^{++} and 10^{-5} M P and at a pH of 7, 30 percent of the phosphate is complexed with calcium. If total calcium is $5x10^{-3}$ M, about 60 percent of the phosphate is complexed. As the pH becomes more alkaline, the product will form a stable crystalline apatite mineral [$Ca_5(OH)(PO_4)_3$]. In water having calcium concentrations of 40 mg/l and a pH of 7, less than 10 mg/l P, or $3.3x10^{-6}$ M PO_4, will remain soluble. New unpublished data collected by the author show that calcium concentrations in Hall County waters are usually greater than 40 mg/l, while phosphate concentrations in some samples exceed 1 mg/l. This implies that apatite precipitation is not controlling phosphate solubility and that, therefore, amorphous precipitates and $CaHPO_4$ aqueous complexes are most likely the contributing species encountered in Hall County groundwater.

Whether the high phosphate concentrations in groundwater are due to natural weathering of the soils or to leaching of phosphate applied as fertilizer cannot be determined from the available data. However, it appears that the Hord-Hall and Valentine-Thurman soil associations have a greater capacity than the Wood River association for rapid downward transport of phosphate. It is the author's contention that high phosphate concentrations in the aquifer beneath the Hord-Hall soils in the vicinities of Wood River and Alda are at least partially a result of fertilizer leachate.

The analytical data for nitrate indicate several zones of high nitrate groundwater beneath the broad terrace (fig. 16). Although point sources for the high concentrations are not clearly defined, several soil associations are quite apparent areal sources. For convenience of reference, four of the high nitrate zones have been given identification designations.

Groundwater in zone TZ-1, the largest of the zones, has an average nitrate concentration of about 50 mg/l. Because the Wood River, which transects the zone, is a losing stream and its flow in dry weather consists mostly or wholly of effluent from sewage treatment plants, Piskin (1973) concluded that the high concentration of nitrate in the groundwater is due largely to seepage from the river. However, the following computations indicate otherwise.

U.S. Geological Survey streamflow data indicate water loss from the Wood River between Gibbon and Alda averages about 2,025 acre-feet per year. Since some of the loss is due to evaporation, the amount of seepage loss is assumed for these computations to be 80 percent of the total, or about 1,620 acre-feet per year. According to Michael Swiggart (personal communication, 1971) effluent from the Wood River sewage treatment plant, which averages 235,000 liters per day, contains 22 mg/l of NO_3-N. Computations based on these data indicate that 8.8×10^9 mg nitrate is added to the groundwater reservoir each year. If this amount of nitrate were to be dissolved in the volume of water generally lost by seepage from the Wood River, the concentration of nitrate in the seepage would be about 4.4 mg/l. The annual quantity of seepage from Wood River is so small compared to the volume of groundwater beneath zone TZ-1 (on the order of 1:10,000) that the increase in the nitrate concentration of the groundwater could not be detected analytically except over very long periods. This would be true even if the added nitrate were to be dispersed by diffusion only; actually, the dispersion process is accelerated by the pumping of groundwater for irrigation. The available data on well depth and nitrate concentrations indicate that the nitrate is fairly well dispersed throughout at least the upper half of the aquifer; none of the sampled wells extends into the lower half.

Effluent from the sewage treatment plant at Shelton is discharged to the Wood River just west of the west county line. Its effect on the nitrate concentration of the groundwater in zone TZ-1 would be similarly negligible.

An important source of nitrate in zone TZ-1 appears to be fertilizer. Because the land area overlying this zone is intensively farmed and constitutes about 7 percent of the total land area of the county, it is logical to assume that at least 7 percent of the total tonnage of fertilizer applied to cropland in the county is applied to the cropland in the area of zone TZ-1. It follows that the amount of fertilizer applied to that area in 1971 was about 1,150 tons. How large a percentage of the nitrogen content of this fertilizer was leached to groundwater as nitrate is unknown. From experiments using a silt loam similar to Hord-Hall soils, Owens (1960) concluded that 5 to 20 percent of the nitrogen applied in the form of fertilizer was leached to a depth greater than 6 feet. In other experiments using a similar soil, Johnston et al. (1965) showed that loss of nitrate-nitrogen definitely is related to the amounts of fertilizer nitrogen and irrigation water that are applied. It is assumed here that an average of 12 percent of the fertilizer applied in 1971 was leached to zone TZ-1; this percentage is equivalent to 1.3×10^{11} mg N or 5.7×10^{11} mg NO_3 reaching the zone of saturation. Assuming further that the added nitrate becomes dispersed throughout the groundwater in the upper half of the zone (estimated at 5×10^{11} liters), the resulting increase in nitrate concentration in that part of the aquifer would be greater than 1 mg/l. Since this zone represents a very extensively cropped and irrigated area in Hall County, this figure may be viewed as a minimum. It is considered significant that from 1960 to 1970 the observed increases in nitrate concentration in water from one well were 22 mg/l and from two other wells were 10 mg/l (fig. 11). If the computations of the increase of nitrate that would result from the application of fertilizer during 1971 are valid, it seems reasonable to conclude that the observed increases were due in large measure to the use of fertilizer.

Leaching of nitrates from human and livestock wastes is a second possible source of nitrate increases in zone TZ-1. However, as already noted, increases in the concentration of chloride, which would be indicative of pollution from these sources are slight in water from zone TZ-1, with the one exception of the small high-chloride plume that probably is due to seepage from the Wood River sewage treatment facility.

Nitrogen naturally present in soils is a third possible source of nitrate in groundwater, particularly in areas where legumes such as alfalfa and clover are grown. Neither of these crops is common in Hall County at the present time. Although dependence on nitrogen fertilizer for crop production is an indication that soils are deficient in nitrogen, the question remains as to how much natural nitrogen once present in the soils has been leached by infiltrating irrigation water. Soil nitrogen data show that the vertical gradient for nitrogen in soils is extremely sharp and that nitrogen concentrations below the root zone are very low. According to Viets and Hageman (1971), leaching of a virgin chernozen soil in which a 6-inch horizon has a bulk density of 2.5 g/cm^3 and a nitrogen concentration of 0.2 percent would result in a nitrogen increment of $4.34x10^{10}$ g [1/] to an underlying groundwater body having the size of zone TZ-1. However, it is doubtful that much of the nitrogen increment would be in the nitrate form. In a discussion of nitrogen loss in relation to nitrate in percolating water, Stout and Burau (1967) concluded that one-fourth of the nitrogen in a virgin soil containing 0.1 percent organic nitrogen would be lost by natural leaching in one hundred years of cultivation and that one one hundredth of that amount would be leached as nitrate. Use of these values results in $1.1x10^8$ g [2/] of nitrogen being leached from each 6-inch soil layer having an initial nitrogen content of 0.2 percent to an underlying groundwater body the size of zone TZ-1. Since the volume of water in zone TZ-1 is about $1.0x1^{-12}$ liters,[3/] the nitrate concentration of water in this zone would increase 1 mg/l annually for each 6-inch layer of soil containing 0.1 percent nitrogen. Leaching under an irrigation regime would be accelerated, thus causing an equivalent nitrate increment in less time. Application of this hypothesis to determine the amount of nitrogen leached as nitrate from soils used for certain crops is of doubtful validity. For example, Hord-Hall soils are used almost exclusively for raising corn and soils so used are stripped rapidly of available nitrogen. However, it is still possible that part of the observed nitrate increase is due to the leaching of natural nitrogen that has been leached below the soil horizons. For definitive separation of the increases due to natural nitrogen and to commercial fertilizer nitrogen, N^{15}/N^{14} ratios would need to be determined.

The increased moisture content that results from irrigation

1/ See appendix D (1.)

2/ See appendix D (2.)

3/ See appendix D (3.)

of soils provides for continuous downward transport of solutes during the growing season. This is an important consequence of the change from dryland farming to irrigation farming, a fact that needs to be considered in studies of groundwater contamination in irrigated areas.

Feedlots are relatively few in the area overlying zone TZ-1. Although they and the Wood River sewage treatment facility contribute some nitrate to groundwater, the amount is believed to be small. From all available evidence, it seems reasonable to conclude that heavy applications of fertilizer in combination with irrigation account for the major part of the nitrate influx to this groundwater zone.

Good evidence that seepage from the Wood River is not a significant source of nitrate in zone TZ-2 is the fact that reaches of the river immediately upgradient and downgradient from zone TZ-2 are neither underlain nor bordered by high nitrate groundwater.

The land area overlying zone TZ-2, like that overlying zone TZ-1, is farmed intensively; much of the acreage is irrigated with water from wells. There are four abandoned feedlots and five operating feedlots containing, in aggregate, about 3,000 head of cattle (Atkinson, 1973). Alda, the only town in the area of zone TZ-2, treats sewage in aerobic lagoons, the effluent from which is applied to the land.

Fertilizer, particularly that applied to the irrigated acreage, and possibly manure accumulations in feedlots are believed to be the principal sources of the nitrate increment in groundwater. Irrigation seepage has also added enough moisture to the soil column to have accelerated leaching of the nitrate that is naturally present in the soil.

Hord-Hall soils near the northwest margin of the broad terrace overlie zone TMZ-1, which contains moderately high concentrations of nitrate. As appears to be true for zone TZ-1, fertilizer applied to irrigated cropland is believed to be the principal source of the nitrates in this zone.

Separating the soils underlain by zone TMZ-1 from the parallel band of Hord-Hall soils underlain by zones TZ-1 and TZ-2 is an area of Wood River soils, which overlie groundwater having low concentrations of nitrate. The coincidence of the one soil association with water high in nitrate and of the other with water low in nitrate is believed to be significant, especially so because agricultural practices on both soil associations are virtually the same. The sharp difference in nitrate concentrations is explained, at least in part, by the following analysis of the chemistry and physics of nitrate transport through the soils.

Differences in the pH and clay content with depth below land surface in the two soil areas are shown graphically in figure 17. As is evident, Hord soils are slightly acid to a depth of at least 30 inches and are slightly alkaline at deeper levels. On the other hand, Wood River soils are close to neutral in the top 20 inches and slightly alkaline below that depth. The clay content also differs markedly. Hord-Hall soils (85% Hord) are about 20 percent clay in their top 20 to 30 inches, with the percentage of clay decreasing at greater depths. Although not appreciably more clayey in the top 15 inches, Wood River soils are much more clayey at depth; a layer about 15 to 35 inches below land surface has a clay content ranging from 34 to 42 percent.

Because the Hord-Hall soils are slightly acidic in their upper layers, the applied anhydrous ammonia fertilizer tends to be in the ammonium form. Nitrogen, as the ammonium ion, will not enter the atmosphere. Hence, the applied fertilizer tends to be held in the upper soil layer until it is nitrified to nitrate. In the nitrate form, the ion is again mobile and is leached downward by infiltrating water or utilized by the crop. There is so little clay in the lower layers of the Hord-Hall soils that downward transport is uninhibited. Thus, theoretically, nitrate enrichment of groundwater is favored by the characteristics of Hord-Hall soils.

The reverse is true of Wood River soils. Because they are alkaline, these soils tend to release relatively more ammonia to the atmosphere. Furthermore, the clayey zone tends to fix the

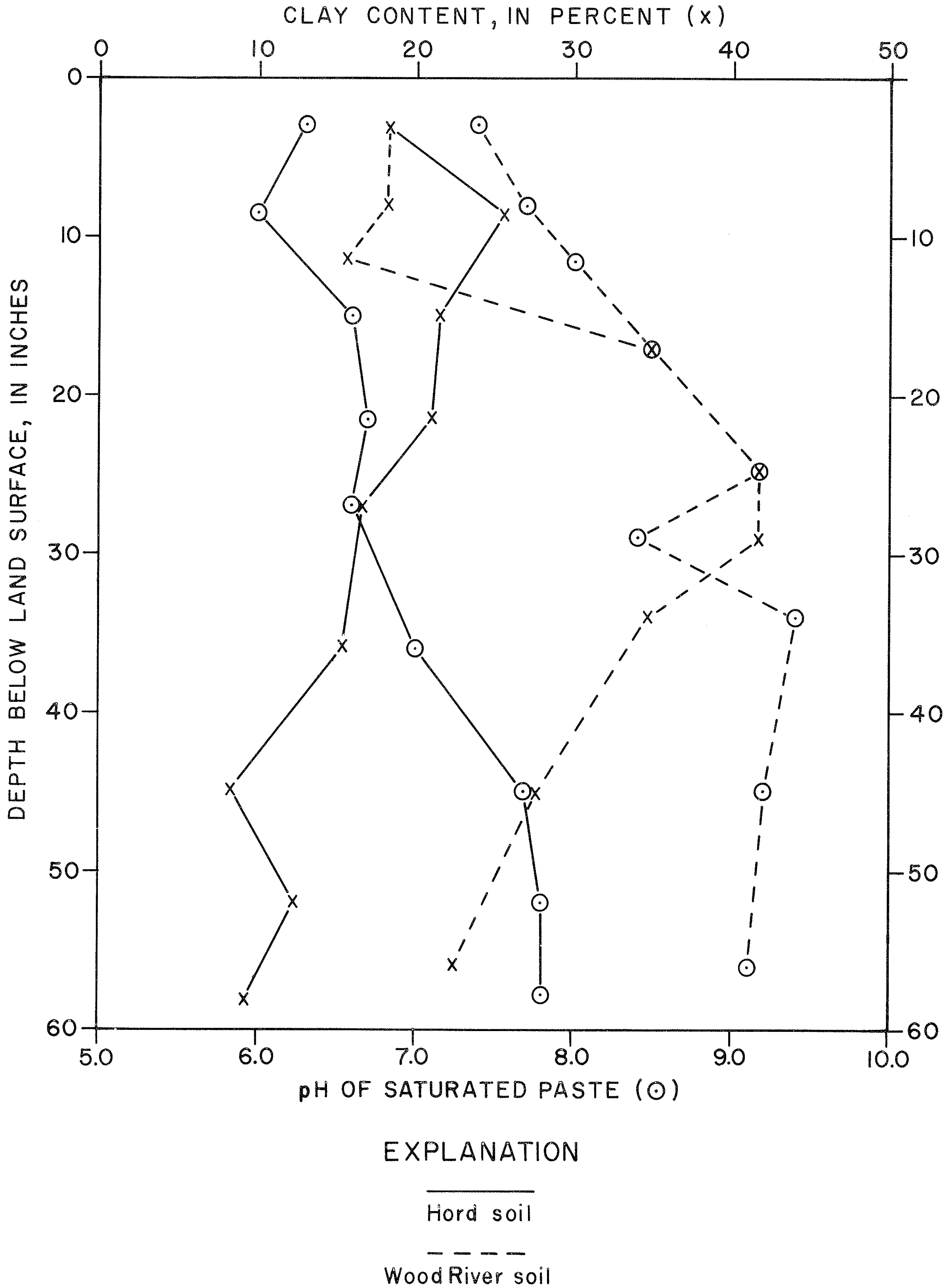

Figure 17.--Clay content and pH of Hord and Wood River soils to depth of 60 inches.

available ammonium ion and also retard downward transport of nitrate-bearing water to the zone of saturation. Of interest in this respect is J. A. Elder's observation (personal communication) that clay horizons become reducing when precipitation or applied water is abundant, increasing the tendency of the reduced ammonium ion to predominate and become fixed.

Compared to Hord-Hall soils, Wood River soils appear to afford better protection to groundwater from nitrate contamination. In view of this desirable characteristic, it is unfortunate that gypsum layers in Wood River soils seem to be dissolving and contaminating the groundwater with excessive concentrations of sulfate.

Most of zone TZ-3 is beneath an area of O'Neill-Meadin soils, which have low natural fertility and are exceedingly well drained. Within this small area (about 2 square miles) are feedlots supporting 1,400 head of cattle. This many cattle could produce 12.2 tons N per year, or as much as 53.7 tons NO_3 per year, and potentially could cause a 4 mg/l annual increase in the nitrate concentration of water in the upper half of the zone. Thus it appears that water infiltrating the manure accumulations has the potential to cause the high nitrate concentrations observed in zone TZ-3. Extremely high nitrate and chloride concentrations in the water sample from well 11N-9W-3DCC indicate that a heavy load of pollutants is coming from either the adjacent feedlot or a nearby faulty septic tank. Since all the sampled wells penetrate only a few feet into the aquifer, it is not known whether high nitrate concentrations also characterize the groundwater at greater depth. Viets and Hageman (1971) report that nitrate stratification occurs within aquifers at some locations, so possibly the high concentrations of nitrate in zone TZ-3 are limited to only its upper part.

High nitrate zone TZ-4 is on the narrow terrace south of the Platte River. Soil overlying this zone is used primarily for irrigated corn. At least one feedlot is within the area, and others are nearby. The highest nitrate concentrations in zone TZ-4 are beneath Hord-Hall and Ortello-Thurman soils. Because these soils are moderately permeable, heavy applications of both fertilizer and irrigation water are necessary to sustain a high level of crop production. It is not surprising, therefore, that nitrates are being leached to the zone of saturation.

In addition to zone TMZ-1, there is one other zone in which the average nitrate concentration is a little greater than 30 mg/l. Designated TMZ-2, this zone extends northeastward from west of Grand Island to the east county line. Were it not for the southeastern part of the Cornhusker Army Ammunition Plant extending into the area between this zone and zone TZ-2, the two zones probably would be continuous. Since there was only limited irrigation within the plant's boundaries until recently, the groundwater underlying the plant area has not become enriched with nitrates.

Soils in the southwestern part of zone TMZ-2 consist predominantly of the Ortello-Thurman association. As previously mentioned, these soils are moderately to highly permeable and nitrate would be leached from them very readily.

The remainder of this zone, in the extreme northeast corner of Hall County, is overlain by soils of three associations--the Exline-Wood River-Silver Creek, the Ortello-Thurman, and the Hord-Hall. The highest concentrations of nitrate in this part of zone TMZ-2 were in water from wells located in the area of Hord-Hall soils. Although fertilizer probably is the principal source of nitrate, sharp differences in concentration from well to well indicate local sources of pollution also are present. Direct contamination resulting from the poor construction of wells and septic tanks may account for some of these differences. At present, sources of the nitrate in this part of the zone can not be determined with any degree of certainty.

Within the upland areas in Hall County, good quality water generally exists. Wells within the uplands are mostly greater than 200 feet in depth. The increased depth appears to be efficiently filtering surface contaminates before they reach the saturated zone. In addition, the uplands are primarily used for grazing and dryland farming. Therefore, they do not receive the heavy loads of fertilizers combined with extensive irrigation that appears to have caused some of the major water-quality problems in the terraces and bottomlands.

CONCLUSION

Groundwater beneath about three-fourths of Hall County is suitable for human consumption, according to commonly accepted upper limits for concentrations of chloride, sulfate, and nitrate. However, concentrations of sulfate and/or nitrate in groundwater beneath the remainder of the county equal or exceed these limits.

The average sulfate concentration in bottomland groundwater is about equal to the 250 mg/l limit for that constituent, and sulfate concentrations in terrace groundwater beneath an area of 16 square miles between Wood River and Cairo range upward from the acceptable limit to a little more than 1,000 mg/l. The source of the sulfate in bottomland groundwater is believed to be influent seepage of Platte River water. Dissolution of gypsum in Wood River subsoils, accelerated by infiltrating irrigation water, is the probable source of sulfate in the terrace area.

Average nitrate concentrations in groundwater beneath areas aggregating about 60 square miles exceed the acceptable limit of 45 mg/l. Widely dispersed sources, namely fertilizer and possibly natural soil nitrogen, appear to be major contributors of nitrate to most high nitrate zones in Hall County. In many places, point sources such as manure leachate and septic tank seepage may be local contributors of nitrate; this is indicated by locally high concentrations of chloride from these same sources. Infiltrating irrigation water probably has increased the rate at which fertilizer and naturally occurring nitrogen is leached from soils. Certain soil characteristics--particularly alkalinity and high clay content--apparently help to forestall nitrate contamination of groundwater.

This baseline study indicates that water-quality problems in Hall County are related to past and present land use practices. Further studies are needed to determine more definitely the extent and sources of existing problems, to assess the potential for aggravation of these problems, and to develop a sound basis for water-quality management.

RECOMMENDATIONS

1. Previous sampling and analyses should be checked throughout Hall County using methods that are acceptable according to the American Public Health Association's Standard Methods for the Examination of Water and Waste Waters and U.S. Environmental Protection Agency standards.

2. Residents of areas underlain by high nitrate zones should be warned of the strong probability that their well water has a nitrate concentration that is about equal to or in excess of the acceptable 45 mg/l limit. This is especially important in areas where the average nitrate concentration of water from the sampled wells was 45 mg/l or greater.

3. In areas where groundwater used for irrigation has a nitrate concentration of 50 mg/l or more, less nitrogen fertilizer should be applied. For example, 150 acre-feet of irrigation water having 50 mg/l nitrate contains 2.3 tons of nitrogen. If this quantity of water were to be applied to 130 acres in a season, the nitrogen added to the soil would amount to 35 pounds per acre, which is approximately equivalent to between 20 and 25 percent of the nitrogen that would be supplied by commercial fertilizer. Theoretically, the nitrogen application could be therefore reduced by this amount. This should decrease the rate of nitrate increase within these high nitrate zones. Another benefit would be the savings in fertilizer expense and a resulting increase in profits.

4. Whether nitrate in groundwater at given locations tends to be stratified or dispersed throughout the full thickness of the aquifer should be determined. Finding that stratification

occurs would be of great significance because supply systems for domestic use could then be designed to draw water from the depth where the nitrate concentration is the least.

5. Differences in groundwater temperature at depth should be measured at selected sites near the Platte River in an effort to determine whether advection currents result from the mixing of river seepage with water already in the bottomland aquifer. Of particular interest would be a determination of the distance from the river that seepage from the river is detectable.

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APPENDIX A

English	Multiplication factor	Metric
acres	4.047×10^{-1}	hectares
	4.047×10^{-3}	square kilometers
acre-feet	1.233×10^{3}	cubic meters
	1.233×10^{-3}	cubic hectometers
acre-feet per mile	7.662×10^{2}	cubic meters per kilometer
feet	3.048×10^{-1}	meters
gallons	3.785	liters
inches	2.54	centimeters
	2.54×10	millimeters
miles	1.609	kilometers
square feet	9.290×10^{-2}	square meters
tons	9.072×10^{2}	kilograms
	9.072×10^{-1}	metric tons

APPENDIX B

1. Calculations of groundwater inflow to and outflow from Hall County

(By Ray Bentall. Based on U.S. Geol. Survey Hydrol. Atlas HA-131, figs. 4 and 5)

Average transmissivity of aquifer beneath west county line south of water-table divide in T. 12 N.:

Width of band 1/ (miles)		Average transmissivity of band (gpd/ft)		Total transmissivity of band (gpd/ft)
1	x	140,000	=	140,000
1	x	40,000	=	40,000
6	x	60,000	=	360,000
2	x	42,500	=	85,000
4	x	57,500	=	230,000
5	x	45,000	=	225,000
2	x	55,000	=	110,000
21				1,190,000

Average transmissivity = 1,190,000 ÷ 21 = 56,700 gpd/ft

Q (Quantity of water)	=	T (Transmissivity, in gpd/ft)		I (Water-table gradient, in ft/mi)	L (Length of aquifer section, in miles)
	=	56,700	x	10	21
	=	11,200,000 gpd			
	=	12,600 acre-ft/yr			

1/ Beginning at south end of west county line

Average transmissivity of aquifer beneath full length of east county line:

Width of band 2/ (miles)		Average transmissivity of band (gpd/ft)		Total transmissivity of band (gpd/ft)
1	x	40,000	=	40,000
2	x	75,000	=	150,000
2	x	125,000	=	250,000
5	x	175,000	=	875,000
4	x	125,000	=	500,000
2	x	175,000	=	350,000
1	x	125,000	=	125,000
6	x	75,000	=	450,000
1	x	40,000	=	40,000
24				2,780,000

Average transmissivity = 2,780,000 ÷ 24 = 116,000 gpd/ft

Q (Quantity of water)	=	T (Transmissivity, in gpd/ft)		I (Water-table gradient, in ft/mi)		L (Length of aquifer section, in miles)
	=	116,000	x	7	x	24
	=	19,500,000 gpd				
	=	21,900 acre-ft/yr				

2. Sample calculation of groundwater-flow velocity

v (Velocity, in ft/day)	=	Q (Quantity of water, in gpd)	/	p (Porosity, in percent)		A (Area of aquifer section, in ft^2)
	=	11,000,000	/	0.30	x	12,000,000
	=	3 ft/day				

2/ Beginning at south end of east county line

APPENDIX C

1. Calculations of nitrogen gains (table 1, p. 26)

Nitrogen from fertilizer:

Total dry mixed fertilizer used in 1971 was 21,460 tons.

As reported by farmers, the preferred dry mix was 7:21:7.

$\therefore$ Tons N/yr = 21,460 tons/yr x 0.07 = 1,502.2

Nitrogen from manure (based on data from McCalla *et al.*, 1970):

Fattening cattle produce about 23,600 g of manure per animal per day.

Average nitrogen content of manure is 14 lbs/ton.

Average number of cattle in Hall County during 1971 was 110,000 (State /Nebraska/-Federal Div. Agr. Statistics, 1973).

$$\therefore \text{Tons N/yr} = \frac{23{,}600 \text{ g}}{\text{day}} \times \frac{14 \text{ lbs N}}{\text{ton}} \times 110{,}000 \times \frac{365 \text{ days}}{\text{year}} \times \frac{1 \text{ ton}}{10^6 \text{ g}} \times \frac{1 \text{ ton}}{2{,}000 \text{ lbs}} = 6{,}632.8$$

Hogs produce about 2,700 g of manure per animal per day.

Average nitrogen content of manure is 10 lbs/ton.

Average number of hogs in Hall County during 1971 was 52,900 (State /Nebraska/-Federal Div. Agr. Statistics, 1973).

$$\therefore \text{Tons N/yr} = \frac{2{,}700 \text{ g}}{\text{day}} \times \frac{10 \text{ lbs N}}{\text{ton}} \times 52{,}900 \times \frac{365 \text{ days}}{\text{year}} \times \frac{1 \text{ ton}}{10^6 \text{ g}} \times \frac{1 \text{ ton}}{2{,}000 \text{ lbs}} = 260.7$$

Nitrogen from human waste (based on data from Am. Water Works Assoc. Tech. Group 2610P, 1967):

Humans produce about 11 lbs of nitrogen per person per year.

Population of Hall County using septic tanks in 1971 was 17,393 (Nebraska Soil and Water Conserv. Comm., 1971).

$$\therefore \text{Tons N/yr} = \frac{11 \text{ lbs N}}{\text{year}} \times 17{,}400 \times \frac{1 \text{ ton}}{2{,}000 \text{ lbs}} = 95.7$$

The remaining population of Hall County is served by community sewage systems. Average daily effluent from the four systems was as follows:

Community	Effluent (gpd)
Grand Island........	2,400,000
Wood River..........	62,000
Doniphan and Cairo..	52,000
Total..........	2,514,000

The nitrogen content of sewage effluent is estimated to be 22 mg/l (McCarty, 1967).

$$\therefore \text{Tons N/yr} = \frac{2{,}514{,}000 \text{ g}}{\text{day}} \times \frac{365 \text{ days}}{\text{year}} \times \frac{22 \times 10^{-3} \text{ g}}{1} \times \frac{3.78 \text{ l}}{\text{g}}$$

$$\times \frac{1 \text{ ton}}{10^{6} \text{ g}} = 76.3$$

Nitrogen from precipitation:

Annual precipitation on Hall County is 24.6 inches. (U.S. Dept. Commerce, Environmental Data Service, 1969).

Concentration of nitrogen in precipitation is 2 mg/l NO_3-N and 3.3 mg/l NH_4-N (Olson et al., 1973), or about 10 lbs N/acre in 24.6 inches of precipitation.

The area of Hall County is 345,000 acres.

$$\therefore \text{Tons N/yr} = \frac{10 \text{ lbs N}}{\text{acre}} \times 345{,}000 \times \frac{1 \text{ ton}}{2{,}000 \text{ lbs}} = 1{,}725$$

2. Calculations of nitrogen losses (table 1, pp. 27, 28)

Nitrogen to the atmosphere:

From fertilizer--

14,273 tons of anhydrous NH_3 plus liquid NH_4OH were applied to Hall County crops in 1971.

An estimated 15 percent of ammoniated products is lost to the atmosphere (Allison, 1965).

$$\therefore \text{Tons N/yr} = 14{,}273 \text{ tons/yr} \times 0.15 = 2{,}141$$

717 tons of NH_4NO_3 were applied to Hall County crops in 1971.

An estimated 10 to 30 percent is lost to the atmosphere by denitrification (biological reduction of NO_3).

$$\therefore \text{Tons N/yr} = 717 \text{ tons/yr} \times 0.20 = 150$$

From feedlots--

Total area of operating feedlots in 1971 was about 1,010 acres (based on the average number of cattle in Hall County feedlots in 1971 and a space allowance of 400 sq. ft. per animal).

Annual loss of nitrogen per acre of feedlot is estimated to be 172 lbs (Elliott and McCalla, 1973).

$$\therefore \text{Tons N/yr} = 1{,}010 \text{ acres} \times \frac{172 \text{ lbs}}{\text{acre}} \times \frac{1 \text{ ton}}{2{,}000 \text{ lbs}} = 87$$

Nitrogen in runoff:

Surface inflow to Hall County contains about 569 kg N/day and surface outflow about 944 kg N/day (Olson *et al*., 1973). The difference--375 kg N/day--is the approximate amount of nitrogen that Hall County loses to surface runoff.

$$\therefore \text{Tons N/yr} = \frac{375 \text{ kg N}}{\text{day}} \times \frac{365 \text{ days}}{\text{year}} \times \frac{2.2 \text{ lbs}}{\text{kg}} \times \frac{1 \text{ ton}}{2{,}000 \text{ lbs}} = 150$$

APPENDIX D

Table 1.--Chemical analyses of water from selected wells in Hall County

(Analyses by U. S. Geological Survey. Results given in milligrams per liter)

Date	Nitrate	Phosphate	Chloride	Sulfate
11N-9W-3DC (Domestic Well)				
1971				
Jan. 28	----	0.44	19.0	---------
Feb. 25	79.0	.49	18.0	---------
Mar. 23	79.0	.21	19.0	72.0
Apr. 23	75.0	.24	20.0	---------
May 20	83.5	.34	19.0	---------
June 24	88.0	.37	24.0	---------
July 22	70.5	.45	22.0	---------
Aug. 19	66.0	.49	19.0	---------
Sept. 15	70.5	.49	20.0	68.0
Oct. 20	64.5	.52	20.0	---------
Nov. 15	70.4	.49	20.0	---------
Dec. 16	64.5	.46	21.0	---------
Average for year	73.7	0.42	20.1	
11N-9W-8DA (Public Supply Well)				
1971				
Jan. 28	25.4	0.58	4.0	---------
Feb. 25	32.8	.80	6.8	---------
Mar. 23	28.8	.37	5.2	27.0
Apr. 22	24.2	.43	5.0	---------
May 19	24.6	.49	4.4	26.0
June 23	25.0	.61	5.2	---------
July 21	27.2	.61	4.5	---------
Aug. 18	25.0	.61	4.3	---------
Sept. 15	27.2	.65	5.6	30.0
Oct. 20	26.8	.64	5.5	---------
Nov. 15	25.9	.64	5.3	---------
Dec. 16	25.0	.67	6.5	---------
Average for year	26.5	0.59	5.2	

Table 1. Chemical analyses of water from selected wells in Hall County--Continued

Date	Nitrate	Phosphate	Chloride	Sulfate
11N-9W-28BB (Public Supply Well)				
1971				
Jan. 27-------------	29.0	0.43	9.8	---------
Feb. 25-------------	40.2	.30	10.4	---------
Mar. 23-------------	31.8	.26	9.6	110.0
Apr. 22-------------	29.5	.20	9.2	---------
May 19--------------	32.5	.27	9.8	120.0
June 23-------------	27.8	.31	10.0	---------
July 21-------------	26.8	.31	9.3	---------
Aug. 18-------------	26.4	.46	9.1	---------
Sept. 15------------	29.5	.43	12.0	120.0
Oct. 20-------------	29.5	.40	11.0	---------
Nov. 15-------------	29.0	.40	11.0	---------
Dec. 16-------------	29.1	.43	12.0	---------
Average for year----	27.7	0.34	10.3	
11N-10W-2DA (Public Supply Well)				
1971				
Jan. 28-------------	36.0	0.52	6.6	---------
Feb. 26-------------	41.4	.49	5.2	---------
Mar. 24-------------	40.0	.67	5.4	---------
Apr. 23-------------	34.9	.34	5.5	---------
May 20--------------	34.4	.64	6.6	---------
June 24-------------	37.5	.61	6.0	---------
July 22-------------	30.5	.61	5.2	---------
Aug. 19-------------	31.2	.67	5.8	---------
Sept. 16------------	31.2	.67	5.8	---------
Oct. 21-------------	31.2	.61	5.4	---------
Nov. 16-------------	32.5	.64	5.2	---------
Dec. 17-------------	31.0	.64	5.8	---------
Average for year----	34.3	0.59	5.5	

Table 1. Chemical analyses of water from selected wells in Hall County--Continued

Date	Nitrate	Phosphate	Chloride	Sulfate
11N-10W-13CC (Public Supply Well)				
1971				
Jan. 27-------------	17.2	0.36	6.8	---------
Feb. 25-------------	27.7	.44	6.4	---------
Mar. 23-------------	24.6	.44	7.2	23.0
Apr. 22-------------	21.0	.29	6.9	---------
May 19--------------	19.2	.43	7.8	22.0
June 23-------------	21.2	.46	7.7	---------
July 21-------------	16.7	.46	7.1	---------
Aug. 18-------------	15.0	.61	7.9	---------
Sept. 15------------	15.4	.55	11.0	23.0
Oct. 20-------------	15.8	.55	9.6	---------
Nov. 15-------------	17.2	.58	9.9	---------
Dec. 16-------------	17.2	.55	10.0	---------
Average for year----	19.0	0.48	8.2	

Table 2.--Chemical analyses of groundwater in Hall County

[Analytical results in milligrams per liter except as indicated. Water use: D, domestic; I, irrigation; O, observation; P, public supply; S, stock]

Well number	Well depth (ft)	Water use	Date sampled	Water temperature (°C)	Total sulfate	Total chloride	Total nitrate plus nitrite	Total orthophosphate	Specific conductance (micromhos)	pH
9-9-1BB	177	I	8-4-71	------	120	15	2.7	0.01	508	7.2
9-9-4DD	180	I	8-4-71	------	340	12	31	.01	945	7.0
9-9-5CD	133	P	8-4-71	------	140	11	30	.10	590	7.0
9-9-8CC	170	I	8-4-71	------	120	7.2	3.5	.06	465	7.2
9-9-14AC	180	I	8-9-71	------	190	15	.9	.10	700	7.2
9-9-21DC	200	I	8-9-71	------	280	9.0	16	.01	790	7.5
9-9-26CA	171	I	8-9-71	------	150	8.5	.3	.01	600	7.3
9-10-2CB	16	S	8-4-71	------	100	13	12	.01	505	7.0
9-10-4CD	92	I	8-4-71	------	300	28	7.5	.02	910	7.4
9-10-6BB	77	I	8-4-71	------	230	19	3.5	.01	700	7.5
9-10-14DC	-----	I	8-4-71	------	68	5.0	.9	.08	510	7.2
9-10-17DD	184	I	8-4-71	------	120	4.2	7.1	.21	545	7.0
9-10-26AC	175	I	8-4-71	------	49	4.6	.3	.08	410	7.2
9-10-28BC	140	I	8-4-71	------	110	6.3	.9	.06	565	7.4
9-11-3AB	-----	I	8-3-71	------	290	25	19	.01	950	7.2
9-11-6BA	60	I	7-20-71	11.1	1200	18	12	.01	1970	7.0
9-11-8BB	70	I	7-20-71	------	370	33	60	.01	1100	7.0
9-11-10CC	22	O	7-6-71	------	300	28	.4	.08	965	8.1
9-11-13AB	84	I	8-4-71	------	270	24	22	.02	945	7.2
9-11-19CC	110	I	8-3-71	------	290	26	12	.02	955	7.5
9-11-20AD	30	D	8-9-71	------	310	30	.3	.07	980	7.6
9-11-25DA	-----	D	8-9-71	------	44	3.8	8.4	.12	525	7.2
9-11-31DD	150	D	8-9-71	------	110	12	12	.11	465	7.3
9-11-34AA	162	D	8-9-71	------	32	6.2	.9	.10	280	7.3
9-12-2CC	52	I	8-3-71	11.7	710	20	3.1	.02	1660	7.6

Table 2--Chemical analyses of groundwater in Hall County--Continued

Well number	Well depth (ft)	Water use	Date sampled	Water temperature (°C)	Total sulfate	Total chloride	Total nitrate plus nitrite	Total orthophosphate	Specific conductance (micromhos)	pH
9-12-5BC	-----	I	8-3-71	-------	150	11	6.2	0.20	640	7.2
9-12-12AB	60	I	8-3-71	-------	370	32	26	.01	1130	7.2
9-12-14AC	62	I	8-3-71	-------	340	33	29	.08	1100	7.3
9-12-20CC	71	I	8-3-71	11.7	290	25	1.3	.01	930	7.6
9-12-21AB	66	I	8-3-71	-------	410	30	12	.02	1230	6.9
9-12-27DC	82	I	8-10-71	-------	270	24	4.9	.02	905	7.5
9-12-32CB	80	I	8-10-71	-------	310	29	20	.05	965	7.2
9-12-35CC	97	I	8-10-71	-------	270	27	12	.04	970	7.2
10-9-1CC1	125	P	7-9-71	11.1	260	23	.4	.04	835	7.8
10-9-1CC2	126	P	7-9-71	12.2	280	27	.4	.16	905	7.8
10-9-2DA	133	P	7-9-71	11.1	260	24	.3	.06	865	7.9
10-9-2DC	130	P	7-9-71	11.7	260	25	.3	.10	875	8.0
10-9-2DD	132	P	7-9-71	13.3	280	27	.3	.17	905	---
10-9-4DD	83	I	7-13-71	-------	180	17	4.9	.02	610	7.2
10-9-11AA	133	P	7-9-71	11.7	260	24	.3	.12	860	7.8
10-9-11AC1	127	P	7-9-71	11.1	280	27	.3	.03	855	8.2
10-9-11AC2	131	P	7-9-71	11.7	170	17	.3	.16	675	7.9
10-9-11BC	130	P	7-9-71	11.1	260	25	.4	.03	770	---
10-9-11BD	137	P	7-9-71	13.3	280	26	.3	.08	900	7.9
10-9-11CA	128	P	7-9-71	11.7	280	26	.4	.02	800	---
10-9-11	-----	P	7-9-71	11.7	300	27	.3	.12	910	---
10-9-13BB	172	I	8-4-71	12.8	240	22	.3	.13	805	7.6
10-9-16CD	65	D	8-4-71	-------	270	25	.4	.02	845	7.4
10-9-25BB	185	I	8-4-71	-------	57	7.6	2.7	.10	405	7.1
10-9-27BB	112	I	8-4-71	-------	230	22	9.7	.02	825	7.2

Table 2--Chemical analyses of groundwater in Hall County--Continued

Well number	Well depth (ft)	Water use	Date sampled	Water temper-ature (°C)	Total sulfate	Total chloride	Total nitrate plus nitrite	Total ortho-phos-phate	Specific conduct-ance (micro-mhos)	pH
10-9-29CB	100	I	8-4-71	------	240	22	0.3	0.22	790	7.4
10-9-32AD	120	I	8-4-71	11.1	270	22	31	.11	885	7.0
10-10-6AD	102	I	7-30-71	------	78	12	32	.42	740	7.7
10-10-8DA	70	I	7-21-71	------	32	5.2	27	.82	440	7.1
10-10-12CC	81	I	7-21-71	------	160	14	22	.02	680	7.3
10-10-20BA	65	I	7-21-71	------	300	15	27	.01	960	7.2
10-10-21CC	60	I	8-2-71	------	270	29	46	.01	1080	7.2
10-10-22AB	50	D	8-2-71	------	240	24	108	.02	1020	7.5
10-10-30CB	60	I	8-2-71	------	230	22	19	.01	805	7.2
10-10-35BB	19	O	7-6-71	------	350	36	.4	.05	1020	7.7
10-11-3BC	80	I	7-30-71	------	65	9.5	30	.68	640	7.2
10-11-9BC	67	I	7-30-71	------	50	11	59	.88	680	7.1
10-11-14CB	54	I	7-20-71	------	40	12	76	.50	485	6.8
10-11-19BD	70	P	7-30-71	------	82	24	34	.92	745	7.0
10-11-19CB	90	P	7-30-71	------	71	22	53	.80	730	7.0
10-11-20DD	100	I	8-3-71	------	48	11	64	.30	565	7.1
10-11-27CB	-----	I	8-3-71	------	370	9.8	11	.34	990	7.0
10-11-30BB	-----	I	7-20-71	11.1	50	9.5	39	.61	625	7.0
10-12-3BC	170	I	7-30-71	------	180	42	20	.20	755	7.3
10-12-7BB	207	I	7-29-71	------	20	4.2	6.2	.20	405	7.3
10-12-14AD	72	I	7-30-71	------	59	8.6	76	.92	665	7.0
10-12-16CC	189	I	7-30-71	------	170	39	1.8	.02	780	7.5
10-12-26CC	60	I	8-3-71	11.7	96	11	65	.92	785	7.3
10-12-28DB	62	I	7-20-71	11.7	100	23	49	1.0	810	7.7
10-12-29BB	61	I	7-20-71	------	250	18	30	.03	920	7.2

Table 2--Chemical analyses of groundwater in Hall County--Continued

Well number	Well depth (ft)	Water use	Date sampled	Water temperature (°C)	Total sulfate	Total chloride	Total nitrate plus nitrite	Total orthophosphate	Specific conductance (micromhos)	pH
11-9-1CC	87	I	8-14-71	11.7	32	13	36	0.28	355	6.9
11-9-2DB	91	I	7-14-71	12.2	32	13	26	.22	355	6.8
11-9-3DB	72	I	8-2-71	12.2	44	9.4	51	.23	450	7.2
11-9-3DC	60	D	7-14-71	------	82	23	87	.18	545	6.8
11-9-4CB	-----	I	7-28-71	11.7	75	10	.9	.03	360	7.0
11-9-5BB	-----	D	7-28-71	------	14	4.0	36	.31	290	6.8
11-9-8CB	-----	P	7-8-71	11.7	29	4.0	20	.38	380	7.7
11-9-8DA	101	P	7-8-71	12.8	17	5.0	23	.33	360	7.7
11-9-10BD	-----	P	7-8-71	------	63	9.7	34	.03	475	7.7
11-9-11DC	50	D	7-26-71	------	250	47	36	.24	1000	6.9
11-9-12DA	100	D	7-26-71	------	82	18	.3	.01	500	7.3
11-9-13CA	70	D	7-26-71	------	110	12	.3	.02	585	7.5
11-9-14DA	90	P	7-8-71	------	170	23	6.2	.03	690	7.2
11-9-23DC	70	I	7-26-71	11.7	220	14	28	.02	850	7.5
11-9-24DD	70	D	7-26-71	------	150	16	36	.02	660	7.2
11-9-25CC	84	I	7-26-71	------	77	11	31	.01	480	7.4
11-9-26CC	76	I	7-15-71	------	180	16	13	.01	650	6.6
11-9-27BB	113	P	7-8-71	12.2	70	9.6	12	.14	520	7.9
11-9-28BB	84	P	7-8-71	12.2	140	9.6	23	.10	615	8.3
11-9-29AC	90	P	7-8-71	------	160	6.1	27	.02	595	---
11-9-29DA	78	P	7-8-71	12.2	140	7.0	12	.01	645	---
11-9-32CC	80	D	7-26-71	------	120	6.1	4.0	.13	580	7.4
11-9-33CB	50	S	7-26-71	11.1	240	14	16	.03	795	7.4
11-9-34CC	65	I	7-15-71	------	410	17	19	.01	1070	6.9
11-9-36BC	64	I	7-15-71	12.2	120	12	34	.02	500	7.8

Table 2--Chemical analyses of groundwater in Hall County--Continued

Well number	Well depth (ft)	Water use	Date sampled	Water temperature (°C)	Total sulfate	Total chloride	Total nitrate plus nitrite	Total orthophosphate	Specific conductance (micromhos)	pH
11-10-2DA	60	D	7-14-71	------	6.3	5.6	30	0.37	290	6.7
11-10-4CC	63	I	7-14-71	11.1	80	13	1.8	.02	415	7.2
11-10-12CC	80	I	7-14-71	11.7	10	8.5	25	.36	305	6.8
11-10-13CA1	-----	P	7-8-71	11.7	14	5.0	22	.38	350	7.6
11-10-13CA2	-----	P	7-8-71	11.7	16	5.9	25	.20	350	7.8
11-10-13CC	106	P	7-8-71	11.7	14	7.1	15	.24	350	7.6
11-10-16CB	90	I	7-19-71	11.7	38	11	3.5	.02	340	7.6
11-10-17AC	64	P	8-19-71	11.1	12	6.3	.3	.17	420	7.4
11-10-18DB	63	P	8-19-71	11.7	12	5.7	6.6	.50	385	7.4
11-10-20BB	60	P	8-19-71	11.7	26	5.6	16	.57	390	7.2
11-10-24CB	60	D	8-26-71	------	7.0	2.4	16	.02	235	7.0
11-10-25BC	100	D	7-26-71	------	25	7.0	26	.40	300	7.0
11-10-28AB	90	I	7-16-71	11.1	41	4.2	7.5	.06	390	7.0
11-10-29BA	60	P	8-19-71	------	40	5.1	15	.47	330	7.1
11-10-29CB	60	P	8-19-71	12.2	17	5.8	20	.78	300	6.8
11-10-34BC	75	I	7-28-71	11.7	41	12	35	.20	500	7.2
11-10-36BC	84	I	7-16-71	10.0	45	5.4	8.4	.19	430	7.0
11-11-4DD	30	D	7-20-71	------	550	50	.3	.02	1280	7.2
11-11-13AA	60	P	8-19-71	11.1	160	20	.3	.07	635	7.3
11-11-13CB	60	P	8-19-71	11.1	69	14	.3	.06	510	7.4
11-11-15AC	52	I	7-20-71	------	360	26	.9	.01	1040	6.9
11-11-17CC	215	I	7-28-71	------	190	14	2.2	.01	780	7.2
11-11-28CC	63	I	7-29-71	11.1	990	54	.3	.01	1900	6.9
11-11-31CC	60	I	7-29-71	11.1	160	55	2.2	.02	940	7.5
11-11-35BC	67	I	7-28-71	11.1	70	9.6	45	.62	610	7.0

Table 2--Chemical analyses of groundwater in Hall County--Continued

Well number	Well depth (ft)	Water use	Date sampled	Water temperature (°C)	Total sulfate	Total chloride	Total nitrate plus nitrite	Total orthophosphate	Specific conductance (micromhos)	pH
11-12-5BC	311	I	7-28-71	12.8	9.0	5.5	2.7	0.01	350	7.3
11-12-9AD	-----	I	7-28-71	13.3	5.0	2.3	1.3	.37	410	7.9
11-12-14CC	60	I	7-28-71	12.2	240	6.5	54	.60	1120	7.3
11-12-18DD	-----	D	7-28-71	------	5.0	4.5	.9	.01	490	7.7
11-12-25BB	150	I	7-29-71	11.1	180	8.8	.4	.01	640	7.3
11-12-29DC	100	D	7-29-71	------	36	3.2	11	.02	410	7.3
12-9-1BC	78	I	7-27-71	11.1	40	4.8	14	.27	485	7.6
12-9-4DD	-----	D	7-27-71	------	6.0	1.8	.3	.38	365	7.4
12-9-13AA	50	O	7-27-71	11.1	54	7.0	12	.68	490	7.7
12-9-15DC	62	I	7-28-71	11.1	67	6.1	16	.48	580	7.2
12-9-25CB	80	I	7-27-71	11.7	61	11	15	.28	590	7.1
12-9-28CC	72	I	7-28-71	11.1	100	15	35	.08	590	7.3
12-9-33DB	90	I	8-2-71	11.1	63	7.0	8.0	.20	510	7.1
12-10-2AB	40	D	7-27-71	------	2.5	2.8	.9	.94	300	7.6
12-10-16CD	78	D	7-19-71	------	1.5	1.7	.9	1.2	265	7.4
12-10-24AA	-----	I	7-16-71	11.1	8.5	2.0	.3	.61	390	7.2
12-10-24BB	65	D	7-27-71	------	4.0	1.8	.3	1.7	325	7.4
12-10-25DD	50	D	7-16-71	------	98	7.1	.3	.20	635	7.0
12-10-26BC	59	I	7-16-71	11.7	7.5	3.2	.3	.60	455	7.2
12-10-31AB	102	D	7-20-71	------	35	17	7.5	.20	680	7.8
12-10-33CB	90	I	7-16-71	11.7	64	6.1	.3	.09	540	7.3
12-10-34BD	85	I	7-20-71	10.6	86	16	21	.12	735	7.2
12-11-2AB	80	D	7-27-71	------	1.0	2.2	16	1.2	150	6.7
12-11-5BC	-----	I	7-27-71	11.1	7.5	1.8	15	.97	210	7.2
12-11-18CC	82	D	7-27-71	------	11	2.2	12	.78	285	7.0

Table 2.--Chemical analyses of groundwater in Hall County--Continued

Well number	Well depth (ft)	Water use	Date sampled	Water temperature (°C)	Total sulfate	Total chloride	Total nitrate plus nitrite	Total orthophosphate	Specific conductance (micromhos)	pH
12-11-21AA	-----	I	7-27-71	12.2	6.5	2.2	.3	1.7	395	7.2
12-11-29AB	94	I	7-28-71	11.1	59	15	.3	.71	710	7.1
12-11-31CC	57	I	7-21-71	12.2	77	5.3	9.3	.04	470	7.2
12-11-36DB	92	I	7-21-71	11.1	120	5.7	.3	.02	460	7.2
12-12-2CB	105	D	7-27-71	-------	3.5	1.3	.3	1.0	325	7.4
12-12-5AC	196	I	7-27-71	12.2	3.5	1.8	3.1	.50	285	7.8
12-12-15DC	-----	D	7-27-71	-------	2.0	1.7	.3	.61	530	7.8
12-12-24AB	118	P	7-27-71	12.2	30	8.0	.3	1.4	580	7.4
12-12-29CC	-----	D	7-28-71	-------	5.5	2.4	7.1	.11	630	7.4
12-12-34AA	212	D	7-28-71	-------	7.5	55	56	.01	670	7.6
12-12-36DD	212	I	7-21-71	12.2	180	24	27	.01	780	7.0

APPENDIX E

1. Calculation of N_2 in a 6-inch soil layer of specified area:

The nitrogen content of a virgin 12-inch soil layer having a bulk density of 2.5 g/cm^3 is assumed to be 0.2 percent (Viets and Hageman, 1971).

The soil area overlying high-nitrate zone TZ-1 is 22 square miles.

$$\therefore N_2 \ g/ft = \frac{0.002 \ g}{g} \times \frac{2.5 \ g}{cm^3} \times 22 \ mi^2 \left(\frac{2.54 \ cm}{in}\right)^3 \times \left(\frac{12 \ in}{ft}\right)^3 \times \left(\frac{5{,}280 \ ft}{mi}\right)^2 = 8.68 \times 10^{10}$$

It follows that the N_2 content of a 6-inch soil is half that of a 1-foot layer of equal area.

$$\therefore N_2 \ g/0.5ft = 4.34 \times 10^{10}$$

2. Calculation of the amount of nitrogen leached as nitrate to the upper half of high nitrate zone TZ-2 if the nitrogen content of the overlying soil is 0.2 percent:

The nitrogen content of a 6-inch soil having an area of 22 square miles is 4.34×10^{10} g.

About one-fourth of the nitrogen content is leached in 100 years and one hundredth of that amount is leached as nitrate (Stout and Burau, 1967).

$$\therefore N = (4.34 \times 10^{10} \ g) \times 1/4 \times 1/100 = 1.08 \times 10^8 \ g$$

3. Calculation of the volume of water in zone TZ-1:

Zone TZ-1 has an area of 22 square miles, an average thickness of about 180 feet, and a porosity of about 0.25.

$$\text{Volume} = \underset{\text{(area)}}{22\ \text{mi}^2} \times \underset{\text{(thickness)}}{180\ \text{ft}} \times \underset{\text{(porosity)}}{0.25} \times (5{,}280\ \text{ft/mi})^2$$

$$= 2.76 \times 10^{10}\ \text{ft}^3$$

$$= 7.8 \times 10^{11}\ \text{liters, or about } 1.0 \times 10^{12}\ \text{liters}$$